Series II, Volume 5 April 25, 1960 Number 4

# BULLETIN

OF THE

## AMERICAN PHYSICAL SOCIETY

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## 1960 SPRING MEETING

AT

WASHINGTON, D.C.

April 25–28, 1960

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# BULLETIN

of the

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April 25, 1960 Series II, Vol. 5, No. 4

# BULLETIN

OF THE

# AMERICAN PHYSICAL SOCIETY

1960 Spring Meeting at Washington, D.C., April 25–28, 1960

OUR Washington meeting now passes into a new phase. *First*, the days of the week will be Monday, Tuesday, Wednesday, and Thursday (but on Thursday we meet in the morning only). The days of the month are the 25th, 26th, 27th, and 28th of April. This choice of dates will make some of our sessions simultaneous with those of the National Academy of Sciences. To mitigate the undesirable effects of this unfortunate but unavoidable coincidence, the programme has been so arranged that many of the invited papers are assigned to the final half-days. Since the last half-day ends around luncheon time, we do not expect the tapering-off in attendance which is so usual a concomitant of the Saturday-afternoon sessions of former meetings. *Second*, all of our sessions are either in the Sheraton-Park Hotel or in the National Bureau of Standards. Though one of the halls at our disposal is literally enormous, we do not have so many other moderately big ones as we should like, and apologies are extended in advance to listeners who may have to stand. These innovations are due to the stringency of the hotel situation in Washington at the end of April. We stand in great debt to our Local Committee, headed as usual by R. D. Huntoon and W. R. Tilley, for having coped so well with the stringency.

The **official hotel** is the Sheraton-Park, already well known to us for many years. It will find rooms in other hotels when its own provision is fully booked. All letters of reservation are to be addressed to it, with mention of the fact that the writer is coming to the meeting of The American Physical Society. Don't put it off!

The **registration desk** will be located in the Esplanade of the Sheraton-Park Hotel—the hall that adjoins Sheraton Hall. There will be no other. Here will be found the usual blackboards for notices of post-deadline papers, unforeseen events or changes in halls, and messages from member to member (but we do not accept messages from those who have not registered). As to the **registration fee**, we are still holding the line at two dollars. Banquet tickets will be sold at the desk.

**Invited papers** are mentioned in the Epitome and listed in the Main Text. We draw particular attention to the two which will be given by recent winners of prizes in the gift of the Society. One of these last is Aage Bohr, who at the banquet will receive the Dannie Heineman Prize for Mathematical Physics, and the other is Donald A. Glaser who at the 1959 December meeting received the 1959 American Physical Society Prize sponsored by Hughes Aircraft Company. The Director-General of CERN will describe recent progress at his famous laboratory. There will be speeches by the two 1959 Nobel laureates, Owen Chamberlain and Emilio Segrè. Note that Session Y begins at the unwontedly early hour of 9 A.M.: this is because we must yield Sheraton Hall at twelve noon.

**The clock has turned back,** and man has bitten dog! There are nineteen fewer contributed papers this year than last, 434 against 453. Incidentally, had this not happened, our members would be spending Thursday afternoon listening to papers instead of visiting the National Gallery of Art; and this is likely enough to happen in 1961. These papers are distributed among thirty-six sessions. For arranging those in theoretical physics we have enjoyed the invaluable aid of T. D. Lee; for the sessions on nuclear interactions and radioactive nuclei and neutron physics, that of C. S. Wu; and for the sessions BA, FA, J, and R, that of P. Kusch. We think that we have done a fairly good job in preventing simultaneities between sessions of similar interest, but probably we shall learn differently when the Bulletin comes out and the complaints come in. Our situation with respect to available rooms will be less favorable on Tuesday than on the other days.

The **banquet** of the Society will be held on *Wednesday* evening (Tuesday might have seemed a more natural choice, but this is the evening of the Academy's dinner), in the Sheraton Hall. Buy your dinner tickets as early as possible and preferably when you register! L. A. DuBridge will be the after-dinner speaker, and the 1960 Dannie Heineman prize will be awarded to Aage Bohr. The banquet will be preceded by a **cocktail party,** and your dinner ticket priced at five dollars will admit you to both (but you cannot get into the cocktail party without the dinner ticket). The cocktails will be served in the Florentine Foyer and Esplanade, just outside of Sheraton Hall. Sometimes we hold the banquet in a relatively small room because of apprehension that not very many will come, but this year there will be practically no limit. There are only two places where a member who comes to the meeting may spend Wednesday evening with propriety: one is the banquet hall; the other is his bedroom, if, but only if, he is suffering from a contagious cold or from some ailment so severe that his physician deters him from leaving it.

The National Bureau of Standards will be host at a **tea** on Tuesday from 4:30 to 6:30 P.M. in the Manse on the Bureau grounds.

A **ladies' programme** is in course of arrangement, and a description thereof will be found on page 304 of this Bulletin.

The American Institute of Physics will conduct a **Placement Service Register** in the Exhibit Hall of the Hotel Sheraton Park, April 25–27, 1960. The Register will be open from 9 A.M. to 6 P.M., Monday, Tuesday, and Wednesday only.

There will be a **book exhibit** in the Florentine Foyer to the Grand Ballroom at which twelve of the leading book publishers will display the latest scientific and technical books and publications. The exhibit will be open from 9 to 5:30, closing at 2 P.M. on Thursday. All are cordially invited to browse.

The **Council of The American Physical Society** will meet at 9:30 A.M. on Monday, April 25, in a place of which notice will be sent to its members.

The **Nominating Committee of The American Physical Society** will meet at 4:00 P.M. on Tuesday, April 26, in a place of which notice will be sent to its members. The Nominating Committee consists of G. E. Uhlenbeck, *Chairman;* H. L. Anderson, T. W. Bonner, Harvey Brooks, M. B. Gottlieb, S. A. Goudsmit, Herbert Leaderman, E. R. Piore, and L. I. Schiff.

**Post-deadline ten-minute papers,** pertaining to very recent achievements of very special significance, will be considered for admission to the programme if abstracts are received not later than Wednesday, April 19, at the office of Dr. R. D. Huntoon, National Bureau of Standards, Washington 25, D.C. The titles of such as may be accepted will be written out on a blackboard near the main registration desk. Session O has been reserved for them, but it is not impossible that some may be placed at the ends of relevant sessions if these are not too long.

The **1960 June meeting in Montreal** is announced on page 304, and attention is very specially called to the **rigorous deadline for hotel reservations.** There will be no Summer Meeting in the West. The 1960 Thanksgiving meeting reverts to the University of Chicago, and a preliminary announcement will be found on page 304. In the June issue of the Bulletin the calendar of meetings and deadlines will be extended to the summer of 1961.

**Announcements of topical conferences** will be found on page 305.

**Instructions for the preparation of abstracts** are printed on page 330 of this Bulletin. Read them carefully, with especial attention to the newer ones printed in italics at the end. Before long, these will be integrated with the main body of the text.

Errata pertaining to abstracts in this issue will be published in a later issue of this Bulletin if received not later than Monday, May 2, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in the abstract defaced with erasures and corrections. Write out your corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW
American Physical Society
Columbia University
New York 27, New York

# EPITOME OF THE 1960 WASHINGTON MEETING

(Personal names are those of invited speakers.)

## Monday Morning

| | | |
|---|---|---|
| 10:00 | A. | Strange particles; Day, Trilling. Sheraton Hall. |
| 10:00 | B. | Apparatus of nuclear physics. Burgundy. |
| 10:15 | BA. | Molecules I. Franklin. |
| 10:00 | C. | Nuclear interactions I. Continental. |
| 10:00 | CA. | Theoretical Physics I: atomic and nuclear theory. Caribar-Mural. |
| 10:30 | D. | Kittel, Bernardes. Adams-Hamilton. |
| 10:15 | DA. | Plasma I. NBS, East Building. |

## Monday Afternoon

| | | |
|---|---|---|
| 2:00 | E. | Plasma II; Griem. NBS, East Building. |
| 2:00 | EA. | Mesons. Burgundy. |
| 2:00 | F. | Helicity; radioactive nuclei I. Adams-Hamilton. |
| 2:00 | FA. | Molecules II; nuclear magnetic resonance. Franklin. |
| 2:00 | G. | Theoretical physics II: nuclear theory; Hayward. Caribar-Mural. |
| 2:00 | H. | Fowler, Parkinson, Nijgh, Brennan. Sheraton Hall. |
| 2:00 | HA. | Nuclear interactions II. Continental. |

## Tuesday Morning

| | | |
|---|---|---|
| 9:30 | I. | Nuclear interactions III. Continental. |
| 9:30 | IA. | Fluid dynamics. NBS, East Building. |
| 10:00 | J. | Paramagnetic resonance. Exhibit Hall. |
| 10:00 | JA. | Radioactive nuclei II. Adams-Hamilton. |
| 10:00 | K. | Theoretical physics II: particle theory. Burgundy. |
| 9:30 | L. | Cosmic rays. Sheraton Hall. |

## Tuesday Afternoon

| | | |
|---|---|---|
| 2:00 | M. | Space physics. Sheraton Hall. |
| 2:00 | MA. | Positrons; general nuclear physics; A. Roberts. Adams-Hamilton. |
| 2:00 | N. | Semiconductors. NBS, East Building. |
| 2:00 | O. | Post-deadline papers, if any. Exhibit Hall. |
| 2:00 | P. | Nuclear interactions IV. Continental. |
| 2:00 | PA. | Theoretical physics IV: Collision processes. Burgundy. |

## Wednesday Morning

| | | |
|---|---|---|
| 9:30 | Q. | Nuclear interactions V. Phillips. Caribar-Mural. |
| 9:45 | QA. | Schiff, Mossbauer, Terrell, Zwanzig. Sheraton Hall. |
| 10:00 | R. | Hyperfine structure and allied topics. Adams-Hamilton. |
| 9:30 | RA. | Jastrow, Singer, Chubb, Newton. Burgundy. |
| 10:00 | S. | Theoretical physics V: many-body problems. Franklin. |
| 9:30 | T. | Levinthal, R. B. Roberts, Dintzis, Randall. Continental. |
| 9:30 | TA. | Solid-state physics I. NBS, East Building. |

## Wednesday Afternoon

2:00 U. Solid-state physics II. NBS, East building.
2:00 UA. High-energy scattering; Rogers. Burgundy.
2:00 V. Theoretical physics VI; field theory. Caribar-Mural.
2:00 VA. Chamberlain, Segrè, Poirier, Glaser. Sheraton Hall.
2:00 W. Optical and general physics. Adams-Hamilton.
2:00 WA. Neutron physics I. Continental.

## Wednesday Evening

6:30 Cocktail party preceding the banquet. Florentine Foyer and Esplanade.
7:30 Banquet of The American Physical Society; DuBridge. Sheraton Hall.

## Thursday Morning

9:30 X. Mueller, Stewart, Allgaier, Zwerdling. NBS, East Building.
10:00 XA. Cryogenics. Caribar-Mural.
9:30 XB. McDonald, Heppner, White, Colgate. Burgundy.
9:00 Y. Aage Bohr. C. J. Bakker, undecided, undecided. Sheraton Hall.
9:30 YA. Nuclear interactions VI: Adams-Hamilton.
9:30 Z. Neutron physics II. Continental.
9:30 ZA. Magnetism. NBS, Materials Testing.

# PROGRAMME

MONDAY MORNING AT 10:00

Sheraton Hall

(L. M. LEDERMAN presiding)

## *Strange Particles*

**A1. $K^-$-Meson Captures by Bound Nucleons in a 200 000-Gauss Field.*** R. STEPHEN WHITE, DANIEL S. FRAED, STANLEY C. FREDEN, AND HAROLD P. FURTH, *Lawrence Radiation Laboratory, Livermore.*—The energy spectrum and charge ratio of $\pi^\pm$ mesons from $K^-$-meson captures on bound nucleons in nuclear emulsion have been studied with the aid of a 200 000 gauss magnetic field. The energies were determined from curvature, ionization, or range. The charges were obtained by curvature or characteristic endings 262 $\pi^-$ and 78 $\pi^+$ meson events are included here. The $K^-$-meson capture events may be divided as follows: (1) $\pi^-$ only in 36 cases and $\pi^+$ only in 22; (2) 44 $\pi^-\Sigma^+$ events and 18 $\pi^+\Sigma^-$ events. $\Sigma^-$ hyperons with one or more prongs are included; (3) 71 $\pi^-H_\rho$ and 31 $\pi^+H_\rho$ events. The $H_\rho$ is a proton or a $\Sigma^-$ hyperon with zero prongs; (4) 111 $\pi^-$ and 17 $\pi^+$ mesons accompanied by 2 or more prongs. There were 6 $\pi^+$ and 42 $\pi^-$ with energies above 90 Mev. 15 $\pi^-$ had energies above 130 Mev. Energy spectra and interpretation are given.

* Work done under the auspices of the U. S. Atomic Energy Commission

**A2. Λ-Hyperon Mass and Production Spectrum from Negative $K$-Meson Reactions with Emulsion Nuclei.*** CONRAD J. MASON, WALTER H. BARKAS, JOHN N. DYER, HARRY H. HECKMAN, NORRIS A. NICKOLS, AND FRANCES M. M. SMITH. *Lawrence Radiation Laboratory, Berkeley.*—In two emulsion stacks exposed to $K^-$ meson beams, a total of 128 Λ-like events have been found by area scanning in the region of stopping $K$ mesons. All of these events have been analyzed, 116 of which proved to be hyperons. The range-measurement techniques employed were essentially those used in determining the range-energy relation for emulsion.[1] The emulsion densities and shrinkage factors for the two stacks were accurately determined in order to obtain reliable results. The first stack yielded a mass value of 1115.30±0.09 Mev (29 events); the second 1115.46±0.09 Mev (87 events). The two results are not inconsistent. The weighted mean for both stacks is 1115.38±0.13 Mev, where the error includes the preceding statistical errors and an 0.12-Mev error arising from systematic effects. This result is tentative pending the outcome of a further study of the pion range-energy relation. The Λ-production spectrum has been obtained in the second stack. Corrections for source space geometry and scanning bias are currently being investigated. It is hoped that not only the corrected production spectrum but also the Λ yield will be available soon.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Barkas, Barrett, Cuer, Heckman, Smith, and Ticho, Nuovo cimento **8**, 185 (1958).

**A3. Parities of Strange Particles.** I. GOLDBERG, *University of Michigan.*—Three reactions have been considered whose analysis should indicate the $K,\Lambda$ and $K,\Sigma$ relative parities. These are

$$K^+ + p \rightarrow 2K^+ + \Lambda$$
$$K^- + n \rightarrow 2\pi^- + \Sigma^+$$
$$\Sigma^+ + p \rightarrow K^0 + 2\Sigma^+.$$

If the first two reactions are carried out a reasonable distance above threshold, the bosons are restricted to $s$ or $d$ states. The $K,\Sigma$ or $K,\Lambda$ relative parity is given by $\omega = (-1)^{L+1}$, where $L$ is the orbital angular momentum of the incoming $K$ and is the angualr momentum of or relative to the center of mass of the two bosons. The third reaction is particularly interesting in terms of high energy $\Sigma$'s produced by large accelerators. The $\Sigma$'s must come out in an odd state and their decay provides a means of determining their spin.

**A4. $\Sigma^\pm$-Hyperon Production and Decay Energetics: Apparent Anomaly in the Reaction $K^- + p \rightarrow \Sigma^- + \pi^+$.*** JOHN N. DYER, WALTER H. BARKAS, HARRY H. HECKMAN, CONRAD J. MASON, NORRIS A. NICKOLS, AND FRANCES M. SMITH. *Lawrence Radiation Laboratory, Berkeley.*—Measurements have been made on production and decay processes of $\Sigma^\pm$ hyperons that presumably overdetermine the masses. From a sample of 634 $\Sigma$ hyperons, the following ranges in standard emulsion have been measured from decay events at rest: $\Sigma^+ \rightarrow p + \pi^0$, 1677±4 $\mu$ (64 events); $\Sigma^+ \rightarrow n + \pi^+$, 9.2363 ±0.0550 cm (23 events). A sample of 61 capture events of $K^-$ mesons by free protons has also been analyzed. Ranges measured were as follows: $K + p \rightarrow \Sigma^+ + \pi^-$, $\Sigma^+$ range, 820.0 ±3.5 $\mu$ (16 events); $\pi^-$ range, 8.8868±0.144 cm (3 events). $K^- + p \rightarrow \Sigma^- + \pi^+$; $\Sigma^-$ range, 711.0±2.3 $\mu$ (35 events); $\pi^+$ range, 7.7980±0.0618 cm (12 events). From the proton decay mode, the mass of $\Sigma^+$ is 1189.30±0.15 Mev: from neutron mode 1188.73±0.50 Mev. Errors quoted are statistical. A small systematic error in pion range-energy relation may be suggested by the difference. Internal consistency is found in the reactions involving the $\Sigma^+$ hyperon, but the measured range of the $\pi^+$ meson in $\Sigma^-$ production is some 3% less than expected. We are studying the possibility that a difference in stopping powers for charges of opposite sign may remove the anomaly. We thank Dr. R. Stephen White for permitting us to measure 21 proton-capture events found by his group.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**A5. $\Sigma^-$ Hyperons from $\pi^-$ On Deuterium.*** P. FRANZINI, A. GARFINKEL, J. KEREN, A. MICHELINI, R. PLANO, A. PRODELL, M. SCHWARTZ,† J. STEINBERGER,† AND S. E. WOLF, *Columbia University and Brookhaven National Laboratory.*—A 12-in. diam, deuterium-filled bubble chamber was exposed to a 1.23 bev/$c$ $\pi^-$ beam at the Cosmotron. This was done to study the production and decay of $\Sigma^-$ hyperons by way of the reactions $\pi^- + n + (p) \rightarrow \Sigma^- + K^0 + (p)$ and $\Sigma^- \rightarrow \pi^- + n$. Measurements by Cronin *et al.*[1] have shown a large polarization of the $\Sigma^+$ from the reaction $\pi^+ + p \rightarrow \Sigma^+ + K^+$. Hence we expect, by charge symmetry, that our $\Sigma^-$'s are highly polarized. Measurement of the decay asymmetry of the $\Sigma^-$ relative to the production plane then yields information on the amount of $s$- and $p$-wave interference in its decay. This information will be presented as will be the production angular distribution.

* Research supported in part by the U. S. Atomic Energy Commission.
† Alfred P. Sloan Fellow.
[1] J. W. Cronin, B. Cork, L. Kerth, W. A. Wenzel, and R. L. Cool, Bull. Am. Phys. Soc. Ser. II, 5, 11 (1960).

**A6. Search for Heavy Meson of Strangeness Two.*** F. T. SHIVELY, R. K. ADAIR, W. CHINOWSKY, AND L. B. LEIPUNER, *Brookhaven National Laboratory.*—The existence of a heavy meson strangeness two and iso-spin zero is compatible with the Gell-Mann-Nishijima scheme, as has been mentioned by Gell-Mann.[1] Interest in this possibility has been stimulated by the possible interpretation of a recent bubble chamber observation at Dubna,[2] as decay of an incident particle to the state $K^0+\pi^+$, and reconsideration of some earlier anomalous events of other groups.[3] The interactions of high energy $K_2^0$-mesons with free protons are being studied using a fourteen inch hydrogen bubble chamber. The proposed heavy meson ($D^+$) may be produced in the strangeness-conserving reaction $K_2^0+p \rightarrow \Lambda^0+D^+$, and can be detected with high efficiency if the $D^+$ mean life $\lesssim 10^{-10}$ sec. A scan of a portion of the pictures has yielded no events interpretable as production and decay of this meson. The presence of one event in these scanned pictures would indicate a production cross section of order 15 $\mu$ barns. The results of further work will be presented.

* Research supported by the U. S. Atomic Energy Commission.
[1] M. Gell-Mann, Nuovo Cimento Suppl. **4**, 848 (1956).
[2] As presented at the High-Energy Physics Conference, Kiev, USSR, 1959.
[3] T. Yamanouchi, Phys. Rev. Letters **3**, 480 (1959).

## *Invited Papers*

**A7. Absorption Mechanism of Negative $K$ Mesons and Pions in Liquid Hydrogen.** T. B. DAY, *University of Maryland.* (30 min.)

**A8. Studies of Strange-Particle Decays with a Xenon Bubble Chamber.** GEORGE TRILLING, *University of Michigan.* (30 min.)

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MONDAY MORNING AT 10:00

Burgundy Room

(H. W. KOCH presiding)

## *Apparatus of Nuclear Physics*

**B1. Magnetic Field Calculations in Scaling Spiral Sector FFAG Magnets.*** S. C. SNOWDON,† *Midwestern Universities Research Association.*—In the design of FFAG magnetic guide fields, it is customary to employ fields that scale, i.e., fields in which the equilibrium orbits for various momenta appear as magnified and rotated images of one another. A method is introduced that permits the determination, in terms of scalar quantities, of magnetic fields generated by spatially distributed currents. An application of this method will be discussed in which the magnetic fields in a scaling spiral sector FFAG magnet are produced by distributed windings located in feeder pole-face slots. The potential grading slots connecting the feeder slots are treated in the fine-grained limit, i.e., the slots are increased in number and reduced in size until a continuous current carrying medium is formed. Relaxation methods using a two-dimensional grid serve to solve the boundary value problem. Computations relative to non-scaling current distributions employing the same general method are in progress.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania.

**B2. Radio-Frequency Self-Tracking in a Synchrotron.*** LEE C. TENG AND E. A. CROSBIE, *Argonne National Laboratory.*—During the acceleration of ions in a synchrotron, after stable radio-frequency ion bunches are established, the average radial position and the average phase relative to the radio frequency in the accelerating cavity of the bunches can be measured by sensing electrodes. This information can be used as feedback controls of the frequency and the voltage of the accelerating radio frequency to form a self-servosystem. Various arrangements of feedback controls are studied analytically. It is shown that for some arrangements and for certain ranges of parameters one can, indeed, obtain stable damped oscillatory solutions for the energy-phase motion of the ion bunch as a whole. This indicates that complete radio-frequency self-tracking can be accomplished with many different arrangements of feedback controls. The merits of each individual arrangement will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**B3. Resonant Beam Extraction from an Alternate Gradient Synchrotron.*** C. L. HAMMER AND L. JACKSON LASLETT, *Iowa State University and Midwestern Universities Research Association.*—A continuation of the work previously reported[1] has shown that if the operating point of an alternating gradient accelerator is moved to the nearest half-integral radial resonance, $\nu_x$, perturbation field-gradients which contain circular functions of arguments $2\nu_x$, $2\nu_x+1$, $2\nu_x+2$ are particularly effective in causing the radial betatron oscillations to grow exponentially at a particular azimuthal position. The analytical procedure for predicting which perturbations give the optimum results, and digital computer calculations verifying these predictions, will be presented.

* Supported by the U. S. Atomic Energy Commission. Computational work performed with the MURA IBM-704 computer.
[1] L. Jackson Laslett and C. L. Hammer, Bull. Am. Phys. Soc. Ser. II, **4**, 268 (1959).

**B4. Quadrupole Focused Betatron with External Injection.** D. DEPACKH, *U. S. Naval Research Laboratory.*—An air-core betatron with alternating quadrupole lenses and having an injection system designed to introduce a large current in a single turn by means of fast pulse techniques has been constructed and has accelerated electrons from an injection energy of 55 kev to a final energy of 2 Mev. The injected current is 0.5 amp. Applications to the storage and acceleration of beams of greatly increased current will be discussed.

**B5. Study of Betatron Oscillations Using Transverse rf Field.*** B. C. COOK, *Midwestern Universities Research Association.*—In order to study the feasibility of using rf voltages to extract beams from accelerators slowly, the dynamics of

particles in an FFAG accelerator has been investigated using a rf probe. In the linear approximation, the width of a resonance in the radial or axial frequency of betatron oscillation to rf knockout (in exact analogy to an optical grating) is $1/m$ where $m$ is the number of times the particle passes the probe at the exact resonant frequency before reaching its stability limit. The coherent motion in this case as well as the incoherent motion due to nonlinear aspects of the dynamics will be discussed. Experimentally both coherent and incoherent effects on the amplitude of betatron oscillations are seen using pulsed rf fields to study the motion. Typical oscillograph traces will be presented and interpreted in terms of the predicted orbits.

* Supported by the U. S. Atomic Energy Commission.

**B6. Production of Monochromatic Photons from Thin Target Bremsstrahlung.*** M. F. Shea, R. L. Walter,† and W. C. Miller, *University of Notre Dame.*—A monochromator has been designed and built to select from the bremsstrahlung produced by our electron accelerator a narrow band of photons of variable energy. The operation of the monochromator has been studied by examining the spectral distribution of the bremsstrahlung itself. Photons produced in a thin gold target (1.7 mg/cm²) were detected in coincidence ($2\tau = 10^{-8}$ sec) with the corresponding inelastic electrons which were momentum analyzed in a modified Koefed-Hanson wedge-shaped magnetic spectrometer. The photons were detected with a 2-in.×2-in. NaI(Tl) crystal and the pulse height spectrum, recorded on a 20-channel pulse height analyzer gated by the coincidence output, was similar to that expected from a line source. The photon energy spread, calculated from the momentum resolution of the electron spectrometer, was about 2%. The relative bremsstrahlung spectral distribution from 0.5 Mev to 1.0 Mev at angles between 0° and 10° was measured for an incident electron kinetic energy of 1.75 Mev and was found to be in agreement with the Sauter distribution.

* Supported in part by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Present address: Department of Physics, University of Wisconsin.

**B7. Glass Scintillators for Neutron Detection.*** G. E. Thomas and L. M. Bollinger, *Argonne National Laboratory,* and R. G. Ginther, *Naval Research Laboratory.*—A wide variety of clear boron- and lithium-containing glass scintillators have been studied as detectors of slow neutrons. Pulse height distributions for neutrons and $\gamma$ rays, the optical transmission of the scintillators, and scintillation decay curves for excitation by neutrons and $\gamma$ rays were measured. Several kinds of both lithium- and boron-containing glasses exhibit excellent properties for slow-neutron detection. They have a high optical transmission for their own radiation. Pulses from neutron capture form a peaked distribution well separated from photomultiplier noise. Thus neutron detection efficiency depends principally on the probability of neutron capture. For some of the boron glasses, the high boron concentration (~0.35 g/cc) implies a detection efficiency per unit volume at least as great as that of any detector now in use for energies less than 1 kev. A partial compensation for the lesser efficiency of the lithium glasses is their much greater pulse height. The decay of the scintillation was studied over the range of time from $10^{-9}$ to $10^{-4}$ sec following excitation. Decay curves for $\gamma$-ray and neutron excitation differ for most glasses, but not enough to permit identification of individual exciting particles by the time dependence of scintillation intensity.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**B8. Scintillation Detector Utilizing Optical Filgers.*** Costa Tsipis and Elihu Boldt, *Rutgers University.*—The detector being developed consists of a block of organic plastic scintillator ($p$-terphenyl in polyvinytoluene with POPOP wavelength shifter) covered by a $4\pi$ anticoincidence shield of scintillation plastic sheeting ($p$-terphenyl in polyvinytoluene with no wavelength shifter). A thin gelatin optical filter (0.1 mm thick) is placed between the central block and the shield. This entire array is viewed externally by two sets of photomultiplier tubes. By means of optical filters, one set of tubes rejects light from the central scintillator but accepts light from the anticoincidence shield. The other set of tubes accepts light arising from the central block. With these two sets of tubes in anticoincidence it is possible to restrict the measurement of scintillation output to those events in which all the charged particles are produced and stopped within the central block. Preliminary investigations on the feasibility of such a detection scheme will be reported.

* Supported by the National Science Foundation.

**B9. Fast Cycling Propane Bubble Chamber.*** D. Tarbell, E. W. Branscomb, L. Gray, E. M. Harth, and J. Leitner, *Syracuse University.*—A 200-cc fast cycling propane bubble chamber was constructed to provide information for the design of a larger chamber, which is to be used in conjunction with new high-energy accelerators of high cycling rates. Since energy input is a major problem for fast cycling operation, a method of storing this energy between expansions was developed; in particular, the kinetic energy of the piston is converted into potential energy of the liquid. Expansion is accomplished by moving one wall of the chamber. A single glass window serves for both illumination and photography. At present the retrodirective system of illumination employs a plane mirror on the piston face, producing a double image of each track; it is thus possible to obtain stereoscopic information from a single photograph. We have found that in order to operate at high cycling rates, it is necessary to minimize spurious boiling caused by constrictions in the operating volume. Since this was done, tracks of excellent quality have been obtained at 2 cy/sec for extended periods. Optimum operating conditions for cycling rates up to 10 cy/sec are now being determined; these will be discussed.

* Work supported by the National Science Foundation.

**B10. Multi-Channel Unit of Junction Counters for Nuclear Spectroscopy.*** O. M. Bilaniuk and B. B. Marsh, *University of Rochester.*—A matrix of twenty 2×12 mm surface junction counters has been constructed for use in the image plane of a magnetic spectrometer. The outputs of individual crystals are displayed in predetermined channels of a 100-channel pulse height analyzer. This is done by connecting separate crystals to successive sections of a delay line[1] and converting the time difference between signals arriving at the ends of the line into pulse heights. Simple procedures for producing reliable Ge-Au surface junctions and contacts and properties of such counters will be discussed. Typical results obtained with this unit will be presented.

* Supported in part by the U. S. Atomic Energy Commission.
[1] This scheme has been suggested independently by D. A. Bromley and W. P. Alford.

**B11. Instrumentation for Medium Energy Gamma-Ray Scattering Measurements.*** E. L. Garwin and A. S. Penfold,† *The University of Illinois.*—A system for the energy analysis of scattered gamma rays of up to 70-Mev energy is described. A 5-in. diam 4-in. long NaI(Tl) crystal is the energy sensitive element. The net amplification between the 10 stage photomultiplier output and the pulse-height analyzer input (sensitivity: 1 v/channel) is 1.8. It is demonstrated that the light-to-voltage transfer characteristic of the photomultiplier is linear at least up to 30 v output levels. The voltage to pulse-height analyzer channel transfer characteris-

tic for the entire electronic system departs from linearity by less than 0.05 channel between the 50th and 16th channel and by 1 channel between the 16th and 6th. Provision for direct determination of the effect of superposed pulses (pileup) is incorporated into the system. Careful shaping of the pulses reduces pileup to a minimum, commensurate with obtaining good resolution from the NaI(Tl) crystal. Some typical pulse height spectra are given, and the novel features of the circuits are described.

* Research supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Litton Industries, Beverly Hills, California.

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## MONDAY MORNING AT 10:15

## Franklin Room

(K. F. HERZFELD presiding)

### *Molecules, I*

**BA1. Dynamic Proton Polarization of Water Vapor Adsorbed on Sucrose Chars.** JAMES J. KREBS, *U. S. Naval Research Laboratory.**—The enhancement of proton polarization of water vapor adsorbed on sucrose chars has been observed. This enhancement has been produced by saturating the forbidden electron nuclear double transition ($\Delta m_s = 1$. $\Delta m_I = \pm 1$). The experiments were performed at room temperature using a 1.5 w *X*-band klystron to feed a cylindrical microwave cavity. The nuclear resonance was observed using a modified Pound-Knight spectrometer. The proton resonance line shape indicated the presence of the adsorbed water in two different environments. The maximum positive and negative enhancements are separated by $(10.4 \pm 0.6)$ gauss in agreement with theory. The enhancement is observed to saturate as a function of microwave power. The maximum polarization produced remains an order of magnitude below the predicted value. The reasons for these last effects will be discussed.

* Work performed as NAS-NRL postdoctoral research associate.

**BA2. Paramagnetic Resonance of a Weakly Coupled Biradical.*** D. H. ANDERSON,† *University of Illinois and Sandia Laboratory,* H. S. GUTOWSKY, *University of Illinois,* AND R. B. SANDIN, *University of Alberta.*—Compounds derived from $\alpha$, $\alpha$, $\beta$, $\beta$-tetrakis-(4-dimethylaminophenyl)-ethylene have been found to be weakly paramagnetic at room temperature. The Lorentzian line shapes and the $g$ values indicate that the paramagnetism is due to exchange of narrowed free radicals. From their molecular structure, the compounds would be expected to have a diamagnetic (singlet) ground state with a low lying excited state having two unpaired electrons (triplet). Consequently, significant increases in paramagnetic resonance intensity with increasing temperature would be expected and were observed for the di-iodide, dinitrate and diperchlorate. Measurements on the polycrystalline di-iodide, for example, yield $g = 2.0033 \pm 0.0004$, line width (maximum slope) $= 2.9 \pm 0.1$ gauss, and the singlet-triplet separation of approximately 0.17 ev (4 kcal/mole). Thus these compounds apparently constitute an intermediate case between the ideal biradical, having independent unpaired electrons, and the triplet, whose unpaired electrons are usually strongly coupled. The variation of line width among the compounds will also be discussed.

* Work supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Present address: Sandia Laboratory, Albuquerque, New Mexico.

**BA3. Rotational Correlation Times for N. M. R. Relaxation.** R. W. MITCHELL AND MELVIN EISNER, *A and M College of Texas.*—The rotational relaxation times for protons in $C_6H_{12}$, $C_6H_6$, and substituted benzenes in solutions of $CS_2$ and $CCl_4$ have been obtained by extrapolation of $T_1$ to infinite dilution. The observed rotational correlation times are not proportional to the volume of the molecule or the solution viscosity, contrary to predictions of the usual theory. A formula obtained from a modification of Hills[1] theory of relaxation is suggested for the correlation time. $\tau = 2I\eta a/\mu kT$, where $I$ is the moment of inertia of the solute molecule, $\eta$ is the solvent viscosity, $a$ is the average radius of the solute molecule, and $\mu$ is the reduced mass of the solvent-solute system. The above formula gives results which are an order of magnitude better than those of the usual theory, and it accounts for the dependence of the correlation time on the size of the solute molecule and the properties of the solvent.

[1] N. E. Hill, Proc. Phys. Soc. (London **67B**, 149 (1954).

**BA4. Deuterium Substitution in the Study of Radiation Induced Organic Free Radicals.*** WALTER GORDY AND ICHIRO MIYAGAWA, *Duke University.*—By repeated treatment with $D_2O$ at ordinary temperatures, the hydrogens of amino or hydroxyl groups in most organic and biochemicals can be replaced by deuterium without a corresponding replacement of the hydrogens bonded to carbon. Since D and H have different nuclear moments, one can, with this treatment, learn whether the amino or hydroxyl hydrogens form a part of the free radicals produced by irradiation of the substance. We have used this method to investigate most of the amino acids, several proteins, and a number of carboxylic acids and amides. Generally, it was found that the labile hydrogens which could be substituted by $D_2O$ treatment do not give an observable hyperfine structure, and thus one can infer that the often observed proton hyperfine structure of the resonance usually arises from hydrocarbon groups in the radicals. A notable exception among the amino acids is glycine, the pattern of which is significantly changed by $D_2O$ treatment. Interestingly, the doublet structure observed for glycylglycine and certain proteins—silk, albumin, pepsin, etc., is not changed by $D_2O$ treatment. This indicates that the doublet arises from a proton bonded to carbon.

* This work was supported by the Air Force Office of Scientific Research and by the Office of Ordnance Research, Department of the Army.

**BA5. Microwave Spectrum and Molecular Structure of Monochloroacetonitrile.*** JACK D. GRAYBEAL, *West Virginia University.*—The microwave spectrum of monochloroacetonitrile has been measured and analyzed. By assuming certain molecular parameters, the structure of the planar framework was determined from the moments of inertia of two isotopic species. The C-Cl and C-C bond lengths were found to be 1.767 A and 1.472 A, respectively. The CCCl angle was found to be 111° 24′. The H···H distance was found to be 1.728 A. The chlorine nuclear quadrupole coupling constant

along the C-Cl bond axis was calculated to be −76.36 Mc. The direction of the dipole moment was estimated to be between the C-Cl and C-CN bond directions, 28° from the latter. The observed C-Cl distance, along with consideration of the observed nuclear quadrupole coupling constants in the solid and gaseous molecules, indicate that there is very little double bond character in the C-Cl bond. The ionic character of the C-Cl bond was estimated to be 18%. The results of this work indicate that one should be cautious about using hyperconjugated structures to describe properties of halomethanes.

* Supported in part by the National Science Foundation.

**BA6. Study of Line Intensities in Pressure-Modulated Vibration-Rotation Spectra.*** RICHARD R. PATTY† AND DUDLEY WILLIAMS, *The Ohio State University.*—Previously described techniques for pressure modulation of infrared absorption spectra have been applied in a semiquantitative study of line intensities throughout vibration-rotation bands of carbon monoxide and nitrous oxide. Calculations of line intensities were made on the basis of an adiabatic pressure cycle; predicted and observed line intensities have been compared. Variations in temperature as well as in pressure directly influence observed line intensities. During a complete cycle of pressure variation, the range of temperatures attained is strongly influenced by the specific heat ratio $\gamma$; it was found that the introduction of argon resulted as expected in an enhancement of the emission spectrum of an entire band as observed by modulation techniques. Other possible uses of monatomic broadening gases in pressure modulation studies will be discussed.

* Supported in part by the Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command.
† National Science Foundation Fellow.

**BA7. Temperature Variation of the Line Width of Collision-Broadened Microwave Absorption Lines.*** J. E. BOGGS, A. P. DEAM, AND J. M. KING, *The University of Texas* (introduced by L. Slutsky).—The dielectric constants at a frequency of 402 Mc/sec of gaseous $CH_3Cl$, $CHCl_2F$, and $CHF_3$ have been measured as a function of pressure over a range of temperature. Each of these gases exhibits dielectric dispersion resulting from pressure-broadened low-frequency molecular transitions. The dispersion curve at each temperature fits the Debye or Cole-Cole equations from which the line-broadening parameter $\Delta\nu/p$ can be determined. The temperature dependence of the line-broadening parameter is discussed in connection with recent theories of collision-broadening of microwave spectra.

* Sponsored by Office of Naval Research contract.

**BA8. Microwave Spectrum and the Stark Effect of $CHClF_2$.*** E. L. BEESON,† T. L. WEATHERLY, AND QUITMAN WILLIAMS, *Georgia Institute of Technology.*—The microwave spectrum of chlorodifluoromethane has been studied in the region from 14 to 38 kMc. The transitions $J_\tau=0_0-1_1$, $1_0-2_1$; $1_{-1}-2_0$, $2_{-2}-3_{-1}$ and $3_1-3_2$ for both $CHCl^{35}F_2$ and $CHCl^{37}F_2$ have been identified by their hyperfine structures. The rotational constants (Mc) are 10 234.7, 4861.2, 3507.7 for $CHCl^{35}F_2$ and 10 233.8, 4717.1, 3432.4 for $CHCl^{37}F_2$. The quadrupole coupling constants (Mc) with respect to the principal axes are $eQV_{aa}=-64.3$, $eQV_{bb}=+35.3$. $eQV_{cc}=+29.0$ for $CHCl^{35}F_2$ and $eQV_{aa}=-51.0$, $eQV_{bb}=28.0$, $eQV_{cc}=+23.0$ for $CHCl^{37}F_2$. From the Stark effect of the $J_\tau=0_0-1_1$ transition the components of the electric dipole moment were found to be $\mu_a=0.12\pm0.02$ Debye and $\mu_c=1.45\pm0.02$ Debye.

* Supported in part by the National Science Foundation.
† Present address: Physics Department, Louisiana State University at New Orleans.

**BA9. Three-Body Recombination of Oxygen Atoms.** ERNEST BAUER, *Aeronutronic,* AND MORRIS SALKOFF, *Institut Pascal, Paris.*—We have made a quantum mechanical perturbed stationary state calculation of the rate of three-body recombination of oxygen atoms in the presence of an oxygen molecule as third body. The recombination is considered to take place into highly vibrationally excited states ($v=9,10$) of the $A^3\Sigma_u^+$ state of $O_2$. There are no adjustable parameters in the calculation: for the interaction potential we have used the results obtained in a previous calculation,[1] which were obtained by comparison with experimental measurements of vibrational relaxation times in oxygen. At temperatures of the order 300–3000°K, the calculated recombination coefficient into these two states is of the order $2-10\times10^{-33}$ cm⁶/sec, which agrees to within better than a factor of 10 with the recent experimental measurements of Camac (Avco/Everett) and Kretschmer (Aerojet).

[1] M. Salkoff and E. Bauer, J. Chem. Phys. 30, 1614 (1959).

**BA10. $O_2$ Vibration Relaxation Rates.*** MORTON CAMAC, *Avco-Everett Research Laboratory.*—The $O_2$ vibration relaxation rates in oxygen-argon mixtures were measured over the temperature range from 1200°K to 7000°K. The relaxation time, $\tau_v$, has the theoretical temperature variation at constant density

$$\log\tau_v=\log A-\tfrac{1}{3}\log T+(B/T)^{\frac{1}{3}}.$$

The experimental data fits this theoretical curve with the constants $A=1.42\times10^{-7}$ cc/particle-sec-(°K)$^{1/6}$ and $B=1.04\times10^7(\pm30\%)$°K for Ar-$O_2$ collisions; while for $O_2$-$O_2$ collisions, $A=7.10\times10^{-7}$ cc/particle-sec-(°K)$^{1/6}$ and $B=1.04+10^7$ °K; $O_2$ is 5.0 times more efficient than argon for producing $O_2$ vibrational relaxation. The theory of Schwartz and Herzfeld predicts $B=9.3\times10^6$ °K in good agreement with the experiment. The experimental results are compared with the theoretical predicted value for $P_{10}$, the fraction of collisions that de-excite the first vibrational state. There is within 50% agreement over the entire temperature range.

* This work was supported jointly by the U. S. Air Force and the U. S. Army.

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## MONDAY MORNING AT 10:00

## Continental Room

## (N. P. HEYDENBURG presiding)

### *Nuclear Interactions, I*

**C1. Precision Measurement of the $(n,p)$ Total Cross Section at 493-kev Neutron Energy.*** C. E. ENGELKE, R. E. BENENSON, AND J. M. LEBOWITZ, *Columbia University.*—The scarcity of accurate total $(n,p)$ cross section measurements between 0.3 and 15 Mev is now the limiting factor in experimentally determining shape dependence of the $(n,p)$ inter-

action. Further data at selected energies can permit extraction of separate singlet and triplet shape dependent coefficients, thereby putting strong conditions on the $(n,p)$ interaction. As a first step the present measurement at 493 kv has been made. Here shape dependence is small enough that an unambiguous singlet effective range can be found establishing a base line for shape dependence measurements. Quotation of results awaits computation of the inscattering correction which requires a six-dimensional numerical integration programmed for the IBM 650. A high-pressure gas scintillator was developed to use the 493-kev resonant neutron capture of the $N^{14}(n,p)$ reaction as an extremely sharp threshold neutron detector. Multiple inscattering is completely negligible although close geometry was necessary for statistical accuracy. Backgrounds of 1 to 2% were measured by reducing neutron energy 15 kev. Count rates were 50 per sec. The transmission of heptane versus a carbon blank was measured. Future measurements in preparation utilize resonances in the $Ne^{20}(n,\alpha)$ reaction.

* This work partially supported by the U. S. Atomic Energy Commission.

**C2. $(n,2n)$ Cross Sections of Deuterium and Beryllium.*** J. LeBlanc, C. Taylor H. Catron, M. Goldberg, R. Hill, J. Stoering, and M. Williamson, *Lawrence Radiation Laboratory, Livermore.*—The absolute $(n,2n)$ cross sections of deuterium and beryllium have been measured for incident neutron energies in the range from 6 to 10 Mev. 1-$\mu$sec bursts of neutrons were produced by the $p(T,n)He^3$ and the $D(D,n)He^3$ reactions using the swept beam of the Livermore variable energy cyclotron. The $(n,2n)$ events are identified by the detection of both of the emitted neutrons in a large liquid scintillator. The scintillator, associated electronics, and their application to $(n,2n)$ cross section measurements have been previously described by Ashby, *et al.*[1] The flux of neutrons incident on the $(n,2n)$ target was measured by means of a small plastic scintillator. This counter was calibrated with respect to a proton recoil[1] telescope using the unswept beam of the cyclotron and then employed as the neutron monitor for pulsed beam operation. The deuterium cross sections at 6.11, 6.55, 7.32, 8.26, and 10.2 Mev are 67, 73, 88, 110, and 140 mb with errors of 10%. The beryllium cross sections at 6.55, 7.32, and 8.26 Mev are 500, 510, and 580 mb with errors of 15%.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] V. J. Ashby, H. C. Catron, L. L. Newkirk, and C. J. Taylor, Phys. Rev. 111, 616 (1958).

**C3. $Be^9$ Photo-Neutron Cross Section near Threshold.*** R. L. Walter,† M. F. Shea, and W. C. Miller, *University of Notre Dame.*—The $Be^9(\gamma,n)$ cross section has been determined, for the 75 kev region above threshold, from an analysis of the integral photo-neutron yield curve obtained using bremsstrahlung produced in a *thin* gold traget by the electron beam from an electrostatic generator. A photon difference method of analysis was used assuming the bremsstrahlung intensity distribution to be linear with a finite high energy limit as indicated by Fano *et al.*[1] The resulting $Be^9(\gamma,n)$ cross section curve rises rapidly to a peak value of 1.2 mb $\pm$10% at 1.69 Mev beyond which it decreases slowly, in good agreement with recent measurements using $\gamma$ rays from radioactive sources. An earlier determination of the $Be^9(\gamma,n)$ cross section made at this laboratory[2] is felt to be incorrect because of the assumptions which were made concerning the shape of the *thick* target bremsstrahlung spectrum.

* Supported in part by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Present address: Department of Physics, University of Wisconsin.
[1] U. Fano, H. W. Koch, and J. W. Motz, Phys. Rev. 112, 1679 (1958).
[2] D. R. Connors and W. C. Miller, Bull. Am. Phys. Soc. Ser. II, 1, 340 (1956).

**C4. Neutrons from the Alpha Bombardment of $Be^9$.*** F. Ajzenberg-Selove, *Haverford College,* and P. H. Stelson, *Oak Ridge National Laboratory.*—Beryllium targets were bombarded by $\alpha$-particles of mean energies 5.6 and 5.78 Mev to determine the relative feeding of the 4.4-Mev and 7.7-Mev states of $C^{12}$ in the $Be^9(\alpha,n)C^{12}$ reaction. This ratio is of importance in determining the decay modes of the 7.7-Mev state which is presumably involved in the buildup of the elements in certain stars.[1] Preliminary measurements of proton recoils in nuclear plates exposed at various angles to the $\alpha$-beam indicate that the ratios are $12\pm3$ at 0° and 90° ($\bar{E}_\alpha$=5.6 Mev) and $18\pm4$ (0°), $16\pm6$ (90°) ($\bar{E}_\alpha$=5.78 Mev). The angular distributions of the two neutron groups are anisotropic. Scanning is continuing to improve the statistics and obtain integrated values of the ratios at the two energies. A previous measurement[2] at $E_\alpha$=5.3 Mev (0°) gave a value of approximately 8 for the ratio.

* Research supported by the National Science Foundation and the U. S. Atomic Energy Commission.
[1] D. E. Alburger, Phys. Rev. Letters 3, 280 (1959).
[2] W. H. Guier, H. W. Bertini, and J. H. Roberts, Phys. Rev. 85, 426 (1952).

**C5. Energy and Angular Distribution of Neutrons Emitted from Be, Co, Mo, Cd, and W.*** J. H. McCrary, J. T. Prud'homme, and I. L. Morgan, *Texas Nuclear Corporation.*—The energy distribution and angular distribution of neutrons emitted from Be, Co, Mo, Cd, and W have been measured for an incident neutron energy of 14.9 Mev. A pulsed beam time of flight neutron spectrometer was used to obtain the energy distributions over an angular region from 30° to 130°. An analysis of the neutrons emitted in the energy interval of 0.50 Mev to 5.0 Mev has been compared with the theoretical predictions of the statistical model. Direct interaction is evident for the emission of the higher energy neutrons.

* Supported by the Advanced Research Project Agency of the Department of Defense and monitored by the Research Directorate AFSWC.

**C6. Evidence for the First Excited State of $He^5$.*** B. O. Hannah,† E. B. Carter, and R. H. Davis, *Florida State University.*—The $Li^7(d,\alpha)He^5$ reaction leading to the ground state and the first excited state of $He^5$ were studied by bombarding natural lithium targets with 120 kev deuterons. To separate the alpha-particle group populating the first excited state from the broad three-bodied breakup continuum due to the $Li^7(d,\alpha)He^4+He^4$ reaction, the alpha-particle yield was measured at 90° to the beam in coincidence with a neutron counter. Bias on the neutron counter was set above the ground state neutron group, i.e. $[Li^7(d,\alpha)He^5, He^5 \rightarrow He^4+n]$. A peak was observed in the coincidence spectrum corresponding to an alpha-particle group populating a first excited state in $He^5$ at about 4.6 Mev with a width of about 3 Mev. A run on a blank aluminum target did not reveal this peak in the coincidence spectrum, and no other reaction is energetically possible at this bombardment energy except $Li^7(d,\alpha)He^5$ and $Li^7(d,n)He^4+He^4$. The estimated upper limit for the ratio of the population of the first excited state to that for the ground state is 1:10.

* Supported by the U. S. Air Force Office of Scientific Research, Air Research and Development Command.
† Now at Knolls Atomic Power Laboratory, Schenectady, New York.

**C7. Elastic Scattering of 31-Mev $He^3$ Ions from Several Elements.*** G. Igo, J. Gonzales-Vidal, and S. Markowitz, *Lawrence Radiation Laboratory, Berkeley.*—Angular distributions of $He^3$ ions scattered elastically from Be, Al, Cu, Sn, and Bi have been measured in the angular range 10° to 100°. The angular resolution of the counting system is one degree at most of the angles and points have been taken at enough angles to define the details of the angular distributions. Cesium iodide crystals which have a thickness slightly larger

than the range of the stopping $He^3$ ions have been chosen as a detector, and the pulse height resolution of the detector is three percent. By using an Al absorber approximately 70 mg/cm² thick, the separation of elastic and inelastic events is considerably improved. The target elements have been chosen so that the elastic and inelastic events can be clearly separated with our energy resolution. The other criterion for the choice of targets was to span the parameter $A^{\frac{1}{3}}$ where $A$ is the atomic number, since optical model analyses are $e$ sensitive to this parameter. The light elements show strong diffraction effects and the heavy element angular distributions are monotonically decreasing at large angles. A comparison will be made between $He^3$ and $He^4$ elastic scattering at comparable energies.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**C8. $Be^9(He^3,T)B^9$ Reaction.*** M. TATCHER, E. BOGART, S. DEVONS, AND L. J. LIDOFSKY, *Columbia University.*—The $Be^9(He^3,T)B^9$ reaction leading to the ground state of $B^9$ was observed at bombarding energies from 2.4 to 4.1 Mev. Since the probability is relatively small that such a reaction will occur through a process involving nuclear penetration and since the initial and final nuclei are members of a mirror pair, having similar wave functions, the study of this reaction should provide information on the properties of the surface region of the nucleus. A 180° double focusing magnetic spectrometer in conjunction with a CsI(Tl) crystal was used to detect the reaction products. At a given magnet setting, tritons were distinguished from the other particles present on the basis of their pulse height in the CsI(Tl) crystal. Excitation functions taken at lab angles of 20°, 40°, 55°, and 90° show a smooth rise with energy in the region explored. Work is in progress to extend the investigation to other mirror nuclei and to increase the useful range of bombarding energy.

* This work partially supported by the U. S. Atomic Energy Commission.

**C9. $(\alpha,t)$ Differential Cross Sections for Several Light Elements.*** J. GONZALES-VIDAL, H. C. CONZETT, AND W. H. WADE,† *Lawrence Radiation Laboratory, Berkeley.*—The energy spectrum and angular distributions of tritons from the bombardment of $Li^7$, $Be^9$, $Al^{27}$, and $Fe^{56}$ with 48 Mev helium ions have been measured. The tritons were identified and discriminated from other hydrogen isotopes by means of an $E-dE/dx$ multiplier circuit.[1] In all the elements studied the $(\alpha,t)$ reaction populates previously known states, though gaps in the energy spectra were observed. The angular distributions are strongly peaked forward and consistent with direct interaction mechanisms. The energy spectra from the reactions and the angular distribution of the reactions leading to some of the low-lying states of the product nuclei will be presented and discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Department of Chemistry, University of Texas, Austin, Texas.
[1] W. L. Briscoe, Rev. Sci. Instr. 29, 401 (1958).

**C10. Deuteron Spectra from Bombardment of $C^{13}$, $N^{14}$, and $N^{15}$ with 48-Mev Helium Ions.*** B. G. HARVEY AND J. CERNY, *Lawrence Radiation Laboratory, Berkeley.*—The energy spectra of deuterons from bombardment of $C^{13}$, $N^{14}$, and $N^{15}$ with 48 Mev helium ions have been measured at many angles between 10° and 100° (laboratory system). Deuterons were identified and measured by means of an $E-dE/dx$ counter telescope and pulse multiplying circuit.[1] The reaction $C^{13}(\alpha,d)N^{14}$ produced deuteron groups corresponding to previously identified $N^{14}$ levels at 0, 3.95, 4.91, or 5.10, 5.68 or 5.83, 6.23, and 8.99 Mev. The deuteron group corresponding to the 2.31-Mev $T=1$ level of $N^{14}$ was not observed; its abundance was less than 3% of the abundance of the ground state group. In all three cases, several well-established low-lying levels of the product nucleus were not populated to a measurable extent. For example, in $N^{15}(\alpha,d)O^{17}$, the levels of $O^{17}$ at 3.07, 3.85, 4.56, 5.08, 5.22, and 5.38 Mev were not populated. All deuteron groups were strongly peaked in the forward direction; angular distributions will be presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. L. Briscoe, Rev. Sci. Instr. 29, 401 (1958).

**C11. Isotopic Spin Selection Rule Violation in the $B^{10}(d,\alpha)Be^8$ Reaction.*** J. R. ERSKINE AND C. P. BROWNE, *University of Notre Dame.*—A study has been made with the Notre Dame broad-range spectrograph of the $B^{10}(d,\alpha)Be^8$ and $Li^6(He^3,p)Be^8$ reactions leading to levels in $Be^8$ between 15.5 and 17.8 Mev. Bombarding energies between 3.8 and 4.25 Mev and observation angles between 35° and 70° were used. In both reactions two levels were observed in $Be^8$ near the excitation where the first $T=1$ level is expected: one at 16.633±0.015 Mev and another at 16.939±0.015 Mev with widths of 95±20 kev and 85±20 kev, respectively. The $Li^6(He^3,p)Be^8$ reaction showed the $1^+$ level at 17.64 but no other close by. Neither reaction showed a level at 16.08. It is not clear whether the 16.633 or the 16.939 is the first $T=1$ level, but is unlikely that both are $T=1$ levels. Preliminary results indicate that the intensity ratio between the 16.633 and 16.939 levels is about unity and nearly the same for both the $(d,\alpha)$ and the $(He^3,p)$ reaction. This suggests a strong violation of the isotopic spin selection rule. This "forbidden" transition has a $3^+(T=0) \rightarrow 2^+(T=1)$ character which distinguishes it from other known $(d,\alpha)$ violations which are obscured by selection rules on angular momentum and parity.

* Supported in part by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.

**C12. Branching Ratio of $B^{10}(n,\alpha)$ Reactions as a Function of Energy for Slow Neutrons.** J. C. YOUNG AND C. W. COOK, *Convair San Diego,** AND R. B. WALTON, *General Atomic.**—The $B^{10}(n,\alpha)Li^7$ and $B^{10}(n,\alpha)Li^{7*}$ reactions have been studied to determine the ratio of alpha-particle decays to the ground state and first excited state of $Li^7$. The ratio has been measured as a function of neutron energy from 0.018 ev to 1 kev. Neutrons were produced by bombarding a lead target, surrounded with polyethylene, with pulses of electrons from a linear accelerator. The reactions were studied using time-of-flight techniques and a 16-m flight path. A $B^{10}F_3$ proportional counter, biased to count both $B^{10}(n,\alpha)Li^7$ and $B^{10}(n,\alpha)Li^{7*}$ events, was used to detect the total number of reactions; a gamma ray detector biased to count only 480-kev gamma rays from the decay of the first excited state of $Li^7$ was used to detect $B^{10}(n,\alpha)Li^{7*}$ reactions observed in a sample of $B^{10}$ powder. Comparison of the number of reactions observed in the two detectors have yielded relative cross-section ratios for the alpha-particle decays. The ratios have been normalized to a value of $\sigma[B^{10}(n,\alpha)Li^7]/\sigma[B^{10}(n,\alpha)Li^{7*}]=6.97\pm0.06\%$[1] obtained for thermal neutrons. The shape of the curve shows only small variations over the energy region studied.

* A Division of General Dynamics Corporation.
[1] J. A. De Juren and H. Rosenwasser, Phys. Rev. 93, 831 (1954).

MONDAY MORNING AT 10:00

Caribar-Mural Room

(G. C. WICK presiding)

## *Theoretical Physics I: Atomic and Nuclear Theory*

**CA1. Calculations of Atomic Energy Levels.***—ALI M. NAQVI, *Thiel College and Harvard Observatory.*—We are calculating the energy levels of highly ionized atoms of intermediate atomic number $Z$, in order to predict the spectral lines of the solar corona in the ultraviolet and infrared regions. Layzer's screening theory has the advantage of simplicity, and it is specially suited for our calculations since its results improve rapidly with increasing $Z$. As a test of this theory we have calculated the interval $^2P_{\frac{1}{2}}-{}^2P_{\frac{3}{2}}$ in the configuration $1s^22s^22p$ of BI isoelectronic sequence. This interval is equal to $1.664\times10^{-6}(Z-s_{2p})^4$ in atomic units, where $s_{2p}$ is the screening of the $2p$ electron. The variational procedure for calculating $Z$-dependent screening constants is discussed. The theoretical interval for BI is 14% off but for Al IX, Si X and P XI the agreement is better than 0.3%. Thus Layzer's theory gives good results for intermediate $Z$. The theoretical intervals for S XII to Sc XVII are given. The work on other sequences is in progress.

* Work supported by a grant from the National Science Foundation.
[1] D. Layzer, Ann. Phys. **8**, 271 (1959).

**CA2. The Energy of Interaction of Two Helium Atoms.***
NEAL MOORE, *Yale University.*—The interaction energy of two helium atoms in the ground state is calculated with a single state function for the entire range of internuclear separations. Use is made of a variational trial function developed in analogy with Hirschfelder and Linnett's treatment of the hydrogen-hydrogen interaction. The results are in good agreement with the best previous treatments in the repulsive region as well as with the results of Rosen, Margenau and Page in the neighborhood of the van der Waals minimum; in addition, information is obtained concerning the instantaneous mutual polarization of the two atoms.

* This work was supported by U. S. Air Force contract and by the National Science Foundation's Fellowship Program.

**CA3. Anomalous Electric-Dipole Internal Conversion.***
E. L. CHURCH, *Frankford Arsenal, and Institute for Theoretical Physics, Copenhagen,* AND J. WENESER, *Brookhaven National Laboratory.*—Internal conversion rates depend on the gamma-ray matrix element plus penetration terms.[1,2,3] If the gamma-ray matrix element is highly forbidden, the penetration matrix elements may lead to observable conversion "anomalies." For electric transitions two types of penetration nuclear elements enter.[2] For electric-dipole transitions these are $\langle \mathbf{j}\cdot\nabla r^k Y_l^m\rangle$ and $\langle \mathbf{j}\cdot\hat{r}r^k Y_l^m\rangle$, approximately. We point out that (1) for El transitions the second penetration matrix element is strongly weighted in the $s_{\frac{1}{2}}\leftrightarrow p_{\frac{1}{2}}$ electron transitions (e.g., $L_{\rm I}$,$L_{\rm II}$ conversion), but weighted much less than the first in other electron transitions. (2) The first matrix element enters in $L_{\rm III}$ about as strongly as in $L_{\rm I}$ and $L_{\rm II}$.[3] (3) With Nilsson wavefunctions, the second matrix element may be much larger than the first. (4) Because of (1), (2) and (3), the magnitude of the observed El$L_{\rm I}$ and $L_{\rm II}$ conversion anomalies, but normal $L_{\rm III}$,[3,4] may now be understood in terms of two penetration matrix elements, and provide additional tests of nuclear models.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] Church and Weneser, Phys. Rev. **104**, 1382 (1956).
[2] Green and Rose, Phys. Rev. **110**, 105 (1958).
[3] Nilsson and Rasmussen, Nuclear Phys. **5**, 617 (1958).
[4] Asaro, Stephens, Hollander, and Perlman, UCRL 8786 (1959).

**CA4. Inelastic Collisions of Electrons with Helium.***
RICHARD AKERIB, *General Dynamics Corporation.*—The cross sections for the inelastic collisions of electrons with helium have been calculated using an impulse approximation.† The formulae are then applied to the excitation of the $3^1P$ state of helium using hydrogenic wave functions with $Z=1$ and $Z=2$ to describe respectively the outer and inner electrons. The results compare favorably with the experimental results of Thieme and Lees. The magnitude of the maximum value of the cross section is nearly equal to the experimental result although shifted to the higher energies by about 25 v. A comparison with the results for hydrogen shows the same effect. The small effect of the interaction of the two bound electrons is being studied.

* Supported in part by Army Rocket and Guided Missile Agency, Redstone Arsenal, Alabama.
† R. Akerib, Ph.D. Thesis, New York University; G. Chew, Phys. Rev. **80**, 196 (1950).

**CA5. Interatomic Repulsive Potentials at Very Small and Intermediate Separations.*** ADOLF A. ABRAHAMSON,† ROBERT D. HATCHER, *New York University,* AND GEORGE H. VINEYARD, *Brookhaven National Laboratory.*—Using a minimal and a maximal principle,[1] respectively, two approximate expressions for the interaction potential between atoms are given such that their mean, $\bar{U}$, differs from the exact value, $U_0$ in the Thomas-Fermi-Dirac (TFD) approximation, by not more than 4% for a two-center system; and by not more than 14%, in the Thomas-Fermi (TF) approximation, for a three-center system. An approximate method for introducing correlation effects is indicated. Applications of $\bar{U}$ to several specific two-center systems show that: (1) For very small separations of less than $\sim0.3a_0$, ($a_0=0.53$ A), $\bar{U}$ agrees well with other theoretical curves and with experiment. (2) In the intermediate range from $\sim0.3a_0$ to $\sim2.85a_0$, $\bar{U}$ agrees better with other theoretical and experimental curves than does either Bohr's screened Coulomb potential or that based on the TF approximation. (3) At separations exceeding the radius $r_0$ of the TFD atom, $\sim2.85a_0$ on the average, the expression for $\bar{U}$ becomes inapplicable.

* This work, performed in part at Brookhaven National Laboratory, was supported by the U. S. Atomic Energy Commission.
† Present address: City College of New York.
[1] O. B. Firsov, Soviet Phys. JETP **5**, 1192 (1957).

**CA6. Electron-Hydrogen Scattering at Low Energies,** TAKASHI OHMURA* AND HARUKO OHMURA,* *National Research Council of Canada.*—The effective range in the singlet system has been evaluated as $2.646\pm0.004$ atomic units by using the asymptotic amplitude of the 202 parameter $H^-$ wavefunction of Pekeris according to the effective range theory.[1] This value of the effective range, together with the value of electron affinity of $H^-$, determines the scattering length in the singlet system as 6.167. The effective range in the triplet system is calculated to be 1.219 atomic units by a Hartree-Fock approximation. It is shown that the effective range approximation is very good for all energies at which only elastic scattering is allowed. The photo-ionization of $H^-$ is discussed on the basis of the effective range theory. The approximate method adopted here is essentially based on the loosely bound nature of the outer electron of $H^-$.

* On leave of absence from Department of Physics, University of Tokyo.
[1] Ohmura, Hara, and Yamanouchi, Prog. Theor. Phys. **20**, 82 (1958).

**CA7. Theory of Long Range Interatomic Forces.*** PETER R. FONTANA, *Yale University.*—The theory of angular momentum suggests general methods for calculating the electrostatic interaction energies between atoms in ground and excited states. In developing these, the effects of spin orbit coupling on the interaction energies have been considered. The use of a coupled representation is only valid as long as the electrostatic interaction is a true perturbation on the system. To investigate the transition from a representation in which spin effects are neglected to the one which includes the spin orbit coupling correctly, a more general perturbation method has been formulated. Attention is given to the interaction energies between an alkali atom in the first excited and another one in a higher excited state. Here a number of energy curves show maxima and minima in first order which are due to the competition of different multipoles. Second order dispersion energies are given to any desired multipole order.

* Work supported by the Office of Naval Research.

**CA8. High Frequency of Bremsstrahlung and the Photoeffect.*** R. H. PRATT, *Stanford University.*—The simple relation[1] between lowest order matrix elements for bremsstrahlung at the high frequency limit and for the atomic photoeffect is shown to be valid also for the terms of relative order $\alpha z$. The complete dependence on principal quantum number of photoeffect from an arbitrary shell may also be obtained to this order; detailed calculations have been made for $S$ and $P$ states in the high energy limit. Extending previous work on the $K$ shell,[2] numerical results have been obtained for the $z$ dependence of the high energy limit of $L$ shell total cross sections. Comparisons will be made with previous theory and with experiment, both for photoeffect from the $L$ shell and for the bremsstrahlung limit.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research.
[1] K. W. McVoy and U. Fano, Phys. Rev. (to be published).
[2] R. H. Pratt, Phys. Rev. (to be published).

**CA9. Interpretation of Isomeric Cross Section Ratios for $(n,\gamma)$ and $(\gamma,n)$ Reactions.*** J. R. HUIZENGA AND R. VANDENBOSCH, *Argonne National Laboratory.*—A statistical model has been used to relate isomeric cross section ratios to the spin dependence of the nuclear level density. The spin dependence was assumed to be of the form

$$\rho(J)\alpha\rho_0(2J+1)\exp\frac{-(J+\frac{1}{2})^2}{2\sigma^2},$$

where $\rho_0$ is the density of levels with $J=0$. Information about $\sigma$ was obtained for several medium and heavy nuclei. The dependence of the isomeric cross section ratios on the multiplicity and multipole character of the gamma ray cascade was also investigated. It was found that although isomeric cross section ratios for neutron capture do not provide precise information about $\sigma$, they often enable one to deduce which of the two possible spin states of the compound nucleus are formed by capture of $s$-wave neutrons in target nuclei with $I\neq 0$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**CA10. Angular Momentum Effects in the Formation and Decay of the Compound Nucleus.*** R. VANDENBOSCH AND J. R. HUIZENGA, *Argonne National Laboratory.*—An analysis of isomeric cross section ratios for the same isomeric pair, $Hg^{197,197m}$, produced by a variety of nuclear reactions has been performed. It has been found that if one takes into account the differences in the distribution of angular momenta brought in by different projectiles, the isomeric cross section ratios are independent of the type of reaction taking place, and depends only on the parameter $\sigma$ characterizing the spin dependence of the nuclear level density. With the assumption that $\sigma$ is independent of excitation energy, a value of $\sigma=4\pm1$ has been obtained from the analysis. This value of $\sigma$ indicates that the effective moment of inertia is considerably less than the rigid body moment of inertia.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**CA11. The Field Theoretic Definition of the Nuclear Potential.*** JOHN M. CHARAP AND MENASHA J. TAUSNER, *University of Chicago.*—A local spin-dependent potential has been calculated, without letting $\mu/M\rightarrow 0$, which is capable of generating the field-theoretic scattering matrix through the two-meson contribution in perturbation theory for energies small compared with the nucleon mass. This is possible because the energy dependence of the iterated Yukawa potential cancels that of the two-meson exchange graphs. In the simpler case of spinless particles a similar cancellation was shown to occur,[1] and then, by a comparison of the dispersion relations and unitarity for the field-theoretic amplitude and the potential scattering amplitude, a definition of the potential independent of perturbation theory was achieved. The extension of these results to spin $-\frac{1}{2}$ particles is nontrivial, for one now has a separate amplitude for each of the five linearly independent spin invariants. Furthermore, one has as yet no proof of nonrelativistic potential theory dispersion relations for the corresponding amplitudes.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. M. Charap and S. P. Fubini, Nuovo cimento 14, 540 (1959).

**CA12. Time Correlation Function for Investigating Three Connected Nuclear Transformations.** W. O. DOGGETT, *North Carolina State College,* AND T. E. TODD, *United States Air Force.*—The dispersion and relative error have been evaluated for a function proposed by one of us (WOD) for determining the true, triple-cascade, nuclear disintegration rate of a constant source of radioactivity. The method consists of breaking the time of an experiment into $N$ intervals of length $t$ and summing individual counts $a_i$, $b_i$, $c_i$ from the $A$, $B$, and $C$ detectors and the products $a_ib_i$, $b_ic_i$, $a_ic_i$, and $a_ib_ic_i$. The average values per interval are inserted into the correlation function

$$\phi=(abc)_{Nt}+2(a)_{Nt}(b)_{Nt}(c)_{Nt}-(a)_{Nt}(bc)_{Nt}-(b)_{Nt}(ac)_{Nt}-(c)_{Nt}(ab)_{Nt}.$$

When each detector sees a member of the same cascade decay, the average value for a large number of intervals is $\phi=\epsilon_a\epsilon_b\epsilon_c m$ where the detector efficiencies appear and $m$ is the average number of $A$-$B$-$C$ cascades completed per interval. When $m\ll 1$ the relative error is $(\epsilon_a\epsilon_b\epsilon_c Nm>^{-1}$, which is identical to the triple coincidence result with negligible coincidences. This technique is free in principle from the usual count-rate restrictions imposed by accidental coincidences or length of daughter half-lives.

MONDAY MORNING AT 10:30

Adams-Hamilton Room

(R. M. BOZORTH presiding)

### *Invited Papers in Solid State Physics*

**D1. Intrinsic Relaxation Processes in Dielectric Ferromagnetic Crystals.** CHARLES KITTEL, *University of California, Berkeley.* (30 min.)

**D2. Solid Helium 3.** NEWTON BERNARDES, *Iowa State University.* (30 min.)

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MONDAY MORNING AT 10:15

National Bureau of Standards, East Building

(A. C. KOLB presiding)

### *Plasma I*

**DA1. Electromagnetic Containment of Charged Particles.** R. W. FREDERICKS, *Thompson Ramo Wooldridge, Inc.* (introduced by B. Hamermesh).—The motion of charged particles in the standing wave field of resonant electromagnetic cavities has been examined. In the case of particles moving under the influence of the $TE_{0,1,m}$ modes of cylindrical or spherical cavities, the equations of motion have been time-averaged to produce two coupled, nonlinear differential equations in which effective binding potential terms appear. By linearizing these two equations, a set of conditions is derived under which the particle dynamical paths become bounded stable orbits of a period which depends upon the initial velocity and position, and upon field strength and driving frequency. These conditions overstabilize the particle motion, since the nonlinear equations may have stable solutions under conditions in which the linearized equations have unstable solutions. Solutions to the linearized equations give information concerning spatial regions of the cavity and electromagnetic and dynamical parameters for which confined particle orbits can can be realized.

**DA2. Forced-Expansion Heating of Thermonuclear Plasmas.** K. C. ROGERS, G. SCHMIDT, D. FINKELSTEIN, AND S. KOSLOV, *Stevens Institute of Technology.*—If an initially hot high-pressure plasma is permitted to expand into a low-field region, as in certain cusp-type experiments, there can be a very large ratio of final to initial volume. If this expansion is adiabatic, it is accompanied by a severe cooling; if free, by no cooling at all. Under certain circumstances, as in CHALICE,[1] it is accompanied by a net heating. In general, heating occurs when the plasma expands from a high-field to a low-field region. In injection methods, where the plasma moves out of a field-free region into the magnetic field, loss of energy is unavoidable. A useful technical device for taking full advantage of this forced-expansion heating is the "vanishing mirror," which is accomplished with low-conductivity flux guides.

[1] D. Finkelstein, S. Koslov, K. C. Rogers, and G. Schmidt, Bull. Am. Phys. Soc. Ser. II, 5, 310 (1960).

**DA3. Parametric and Scaling Relations for Plasma Production by Neutral Atom Injection,*** R. F. POST AND C. C. DAMM, *Lawrence Radiation Laboratory.*—In principle, a dense high temperature plasma can be generated in a "magnetic bottle" by the following means: An intense beam of energetic hydrogen atoms is injected through the magnetic field, passing diametrically across the confinement chamber. Trapped ions and electrons resulting from the ionization of an arbitrarily small fraction of the beam in transit act as new centers for ionization. If their rate of producing new ions exceeds their rate of loss by charge exchange on residual gas atoms, exponentiation of the trapped charge density up to a limiting value can occur. This condition defines a critical neutral particle density which is a function of particle energy, plasma volume, magnetic field strength, and other parameters. A simple differential equation, for the buildup, which applies to the Mirror Machine is solved, and its solutions are expressed in terms of these parameters. Study of the scaling laws indicated by these solutions shows that the critical conditions are more easily met if injected atom energies of about 20 kev are used, in contrast to the conclusions of earlier studies. Also, it is shown that high magnetic fields are advantageous.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**DA4. High-Energy Plasma Production by Neutral Atom Injection.*** A. H. FUTCH, C. C. DAMM, W. HECKROTTE, AND J. KILLEEN, *Lawrence Radiation Laboratory, Livermore.*—The differential equations and their solutions for the formation of a high-energy plasma by the injection and trapping of energetic atoms in a magnetic mirror geometry are discussed. The trapping mechanism is the ionization of the atoms by collisions with background gas molecules and with previously trapped ions and electrons, as described in the previous abstract. An earlier treatment has been given by Gibson *et al.*[1] The present approach includes the finite orbit size of the ions and the spatial dependence of the trapping process in the equations. In addition, the effect of charge-exchange of the trapped ions with the beam atoms has been evaluated. It has been shown that, for suitable experimental conditions, this latter process increases the ion density in the plasma core and results in less stringent conditions for the achievement of exponential plasma growth to high density levels. Numerical solutions have been obtained.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] G. Gibson, W. A. S. Lamb, and E. J. Lauer, Phys. Rev. 114, 937 (1959).

**DA5. Sufficient Conditions for Hydromagnetic Stability of a Diffuse Linear Pinch.*** HAROLD P. FURTH, *Lawrence Radiation Laboratory, Livermore.*—In the energy integral for a hydromagnetic configuration with pinch-type symmetry[1] the

integrand has the form $f(\xi')^2+g\xi^2$, where $\xi(r)$ is the arbitrary displacement and $f$, $g$, are functions of $B_z$, $B_\theta$, $r$, $m$, and $k$. The integrand can be rewritten identically as $(f^{\frac{1}{2}}\xi'+u\xi)^2+[g-u^2+(f^{\frac{1}{2}}u)']\xi^2$, where $u$ is a function of $B_z$, $B_\theta$, $r$, $m$, and $k$ that is disposable within certain restrictions on its boundedness. Accordingly, the condition $g-u^2+(f^{\frac{1}{2}}u)'>0$ is sufficient for stability. W. A. Newcomb has shown that if the specifications on $B_z$, $B_\theta$ are complete, the present treatment is equivalent to the Euler-Lagrange treatment, and the existence of a properly bounded $u$ satisfying the inequality is necessary and sufficient for stability. If only certain bounds on $B_\theta$, $B_z$, and their derivatives are specified, suitable choices of $u$ lead to sufficient criteria of enhanced generality (which are not, in general, necessary criteria). The latter approach is illustrated on the important case of the hard-core pinch with current flow orthogonal to magnetic field.[2]

* This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] W. A. Newcomb, *Hydromagnetic Stability of a Diffuse Linear Pinch* (University of California Radiation Laboratory, UCRL-5447, 1959) (to be published in Ann. Phys.).

[2] S. A. Colgate and H. P. Furth, *Stabilization of Pinch Discharges* (University of California Radiation Laboratory, UCRL-5862, 1960) (to be published in Phys. Fluids).

**DA6. Wake of a Charged Body Moving in a Plasma.*** E. H. WALKER AND S. F. SINGER, *University of Maryland.*—The earlier theory[1] has been extended to the case where the magnetic field and velocity vector of the body are no longer parallel, and where the field in addition is nonhomogeneous. In this manner we approach the case of a charged satellite moving in the earth's outer ionosphere. As distinct from the case of parallel and homogeneous field, the charge cloud now detaches from the satellite but produces peculiar condensations of plasma which bear a fixed relation to the satellite, and may be termed "ghosts." Under nonsteady-state conditions this relationship changes and "ghosts" can travel with respect to the satellite. We discuss some of the interesting properties, particularly as they relate to radar observations. We also present more detailed results on the distribution of charge around the satellite. An important application of this work is to the question of the electric drag of an earth satellite.

* Supported in part by a research grant of the Douglas Aircraft Company.

[1] E. H. Walker and S. F. Singer, Bull. Am. Phys. Soc. Ser. II, 5, 47 (1960).

**DA7. Electric Field Distribution in a Dense Plasma.** JULIUS L. JACKSON, *National Bureau of Standards.*—A calculation has been made of the probability distribution function of the electric field at the center of a spherical ion or atom in an idealized dense plasma (or ionic solution). The novel feature of this calculation is that the net charge densities in the medium are taken as random variables rather than the positions of the charges. The probability distribution function of the net charge is obtained from the Helmholtz free energy. The Helmholtz free energy is written using the exact Coulomb interaction and an expansion of the entropy up to the quadratic term in the net charge density. One thus obtains, in this approximation, a Gaussian distribution for the net charge. Thus the field, as it is a linear function of the charge density, is also Gaussian. The model has obvious limitations but it allows one to see explicitly the effect of the Coulomb interactions.

**DA8. Diffusion of a Magnetic Field into a Plasma.*** RICHARD L. MOORE, *Richard L. Moore Consultants.*—The angular momentum transfer at the surface of a plasma with cylindrical symmetry, due to electrons being reflected at the magnetic field ($B_z$)-plasma interface is obtained from the value of the surface current, $i_\theta$, the average life of the electron at the interface, and the electron flux. The net torque, $\mathbf{r}\times\mathbf{F}$, for a plasma with no internal angular momentum is proportional to $r^2\bar{H}_z\Delta H_z$. This torque induces rotational currents in the electron gas. The result is the apparent diffusion of the $B_z$ field into the plasma, since these currents induce a field for a stationary observer inside the plasma. These currents persist as long as the internal electron angular momentum flux is different from the applied moment.

* Work supported by Norair Division, Northrop Corporation.

**DA9. Plasma Motion Across Magnetic Fields.*** GEORGE SCHMIDT, *Stevens Institute of Technology.*—The analysis of plasma flow problems in magnetic fields is usually based on a hydromagnetic fluid model. In low density collisionless plasmas, however, the limitations of the applicability of this method are not clearly understood. A simple model is proposed which takes into account the motion of single particles, in the self-consistent field produced by all the particles, in the guiding center approximation. In this case the high "dielectric constant" of the magnetoplasma plays the role of the infinite conductivity of the fluid model. Several experiments are analyzed on the basis of this model and the limitations and shortcomings of the hydromagnetic treatment discussed.

* Supported by the U. S. Atomic Energy Commission.

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## MONDAY AFTERNOON AT 2:00

## National Bureau of Standards, East Building

## (M. B. GOTTLIEB presiding)

## *Plasma II*

**E1. Asymmetric Broadening of the $H_\beta$ Line by a Plasma.*** ROGER M. HERMAN, *Yale University.*—Observations of the $H_\beta$ line emitted from plasmas have revealed asymmetric line shapes, the intensity of the blue wing being up to 10% greater than that of the red, for ion densities near $10^{17}$ cm$^{-3}$ and approximate temperature 13 000°K. Possible causes of the asymmetry are examined and their effects are compared. It is found that the inhomogeneity of the ionic fields within the plasma plays an important role in the asymmetric broadening. If we assume that the ionic fields are governed by Holtsmark statistics, we make an estimate of the field inhomogeneity as a function of field strength. Detailed calculation of the line shapes, based on statistical theory alone, shows good qualitative agreement with the observed contours. the calculated being somewhat greater than the observed asymmetry.

* Work supported by Office of Naval Research.

**E2. Statistical Line Broadening in Plasmas.*** HERMANN K. WIMMEL, *Yale University* (introduced by Henry Margenau).—The conditions under which ion broadening of spectral lines emitted from plasmas can be described by the statistical

theory are investigated by studying the fluctuations of the electric microfield acting on a radiating atom. We assume classical paths and absence of interaction between perturbers. The Fourier integral formula reveals three effects that cause deviations from the statistical line shape. Two of them, diabaticity and radiator rotation, are negligible compared to the third, whenever the total deviations are small. The third effect arises from the loss of phase coherence occurring in a characteristic time $T_\phi(F)$ related to the mean lifetime $T_F$ and the adiabaticity parameter $\delta(F)$ of a given electric microfield $F$. Our final expression satisfies the wing theorem and likewise reduces to Holtsmark's line shape for high densities and low temperatures. The deviations from the statistical line shape depend on the reduced fieldstrength and the ratio of a certain field-fluctuation frequency to the Stark frequency shift.

* Supported by the U. S. Air Force Office of Scientific Research and the Office of Naval Research.

**E3. Spectral Characteristics of Cyclotron Radiation from a Hot Plasma.*** LUDWIG OSTER, *Yale University* (sponsored by David Mintzer).—Since the spectral characteristics of cyclotron radiation depend strongly on energy and density of the emitting particles, the question arises as to whether it can be used as a means for determining temperature and density of a given plasma—for instance, in a thermofusion experiment. An attempt is made to give a general description of the spectral behavior of cyclotron radiation under various external conditions, such as mean density, energy, and energy distribution of emitting particles. The influence of field inhomogenities as well as of collisions is taken into account. Finally, the relative importance of cyclotron radiation with respect to other types, such as free-free and free-bound radiation, is discussed.

* Supported by the Office of Naval Research.

**E4. Spectral Analysis of the Plasma Radiation,*** A. ISIHARA, *Polytechnic Institute of Brooklyn.*—The plasma radiation is determined by the net time change of the distribution function for one particle.[1] The differential equation to determine the distribution function is nonlinear and it is necessary to introduce simplifying assumptions. However, without making such assumptions, it is possible to derive the dynamical equation taking the moment of the differential equation. This dynamical equation is used to find the macroscopic description of the angular and the spectral distribution of the plasma radiation. It is found that the radiation depends on the Fourier components of the stress tensor and is propagated in the direction determined by the tensor and the position of the observer. The total radiation power of wave of frequency $\omega$ which is propagated in the direction is proportional to the square of the product of $\omega$ with the Fourier component of the stress tensor.

* This work was supported by the U. S. Air Force through the Office of Scientific Research.

[1] A. Isihara, Bull. Am. Phys. Soc. Ser. II, 5, 79 (1960).

**E5. Enhancement of Luminescence by Microwave Action on Flames.*** JENNY E. ROSENTHAL, *Bramley Consultants.*—Soviet Physics reported that in a thermonuclear reactor a microwave field may produce both the temperature rise and the necessary thermal insulation, i.e., confinement of the plasma. We made observations on the brightness increase of a flame placed in a microwave field. A bright (7000-ft-c) sodium flame formed by an oxyhydrogen torch saturated with NaCl was placed inside and perpendicular to the waveguide of a magnetron operating CW at 3 kMc and 800 w. When the electric vector was perpendicular to the direction of gas flow, we observed a 16-fold increase in brightness corresponding to an increase in plasma energy. Work with pulsed microwave fields was carried out at too low an average power for strong brightness increase, but the observed enhancement was synchronized with the field pulses ($\frac{3}{4}$ $\mu$sec duration at 2000 cps). Calculations by R. Kraushaar indicate that the skin effect analogy is inapplicable and that for suitable orientation of the microwave field with respect to the sheath, the field should not be reflected appreciably from the plasma.

* Under contract to ACF Electronics, Paramus, New Jersey.

**E6. Ion Diagnostics in Controlled Thermonuclear Experiments.*** WILLIAM R. SNOW AND J. A. RUTHERFORD, *General Atomic.*†—In order to provide additional information in controlled thermonuclear experiments, studies of the ions leaking from various experimental devices have been initiated. In these studies, the ions enter a differentially pumped vacuum chamber where the ions are passed first through a transverse magnetic field, which selects a particular ion momentum, and then through an electrostatic field which selects the ions according to energy. The ions are detected by an electron multiplier. From measurements of both momentum and energy, the ion mass is uniquely determined also, and significant information is obtained from the time of arrival of the ions at the detector. In addition to discussing the experimental techniques, results of studies on a plasma injector, where both mirror and cusp magnetic field geometries were employed, and a linear pinch will be presented and discussed.

* This work was carried out under a joint General Atomic-Texas Atomic Energy Research Foundation program on controlled thermonuclear reactions.

† Division of General Dynamics Corporation.

**E7. A New Microwave Diagnostic Method for Dense Plasmas.** R. M. GALLET, J. M. RICHARDSON, B. WIEDER, AND G. D. WARD, *National Bureau of Standards, Boulder Laboratories.*—Microwave methods generally require frequencies above the plasma frequency in order to penetrate the medium. For dense plasmas this requires submillimeter waves for which convenient techniques are not available. The authors have proposed the use of the "whistler mode" of propagation through a dense plasma and have performed a series of experiments confirming many properties of this mode using the plasma of the thermonuclear machine ZETA at Harwell, England. The principal advantage is to permit propagation inside the plasma at frequencies between zero and the electron gyro-frequency, whatever the electron density. For the conditions chosen, the refractive index becomes very large, of the order of 100. The very great anisotropy of the propagation mode furnishes interesting directive properties in the general direction of the magnetic field. Experiments at two frequencies simultaneously around 3000 Mc included observation of the desired mode over distances up to 125 cm as the magnetic field grows and decays; demonstration of coherence throughout the propagation by the production of interference fringes, thus establishing the possibility of direct measurement of phase index; and simultaneous measurement of field by flux coil and gyrofrequency observation.

**E8. On Large-Amplitude Plasma-Magnetic Waves** MARIAN H. ROSE, *New York University.*—This investigation is concerned with the possible existence of a shock in a collisionless plasma subjected to a magnetic field. The simplest case is that of a two-component system, electrically neutral, whose motion takes place in a plane perpendicular to the magnetic field. By transforming to a "shock" frame of reference it is possible to reduce the problem to one independent variable. The basic equations are those of conservation of mass, momentum and energy together with Maxwell's equations. The stress and heat flow terms in the conservation equations are derived from guiding-center theory. As already shown by several investigators who used a lower order version of these equations, the singularity at the back of the "shock" is vortex-like, that ahead is saddle-like, hence to this approxi-

mation the only possible transition is a pulse. By including higher order terms (i.e., stress terms), it is shown that a necessary condition for a shock, namely, the opening up of the vortex into a spiral, does not occur. Indeed, the equations remain symmetric to all orders which shows that they do not contain the necessary damping mechanism.

**E9. Two Errors Commonly Made in Controlled Thermonuclear Reaction Research.** JOSEPH SLEPIAN, *1115 Lancaster St., Pittsburgh 18, Pennsylvania.*—At the 1959 Spring Meeting[1] I pointed out the seriousness of the error made in treating the motion of plasmas in electric and magnetic fields in neglecting the $\rho\vartheta\cdot\nabla\vartheta$ term[2] in the equation of motion of the ionized gas. I now speak of the error made dealing with the total current density in a plasma and calculating the momentum changing force of the electrons upon the ions in moving with a relative velocity referred to the ions. This force for many practical cases is given by $P_{ei}=ne/c[\vartheta\times B]$ and must carefully be included. When properly included, it shows that the containment of a plasma by a magnetic field alone is an unrealized dream. The way to utilization of thermonuclear power is by means of a flow through a high electric and magnetic field as is done by means of the Ionic Centrifuge.

[1] Joseph Slepian, Bull. Am. Phys. Soc. Ser. II, **4**, 4,247 (1959).
[2] The notation used is that of L. Spitzer, Jr., *Physics of Fully Ionized Gases* (Interscience Publishers, Inc., New York, 1956).

### *Invited Paper*

**E10. Plasma Densities and Temperatures from Line Profiles and Intensities.** H. R. GRIEM, *Naval Research Laboratory and University of Maryland.* (30 min.)

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## MONDAY AFTERNOON AT 2:00

## Burgundy Room

## (R. J. PLANO presiding)

### *Mesons*

**EA1. Photoproduction of Meson Pairs from Deuterium.*** R. M. SCHECTMAN, B. M. CHASAN, G. COCCONI, V. T. COCCONI, AND D. H. WHITE, *Cornell University.*—A 24-in. diffusion cloud chamber with a 6-kgauss-magnetic field was filled with tritium-free deuterium and exposed to a 1050-Mev LiH-hardened bremsstrahlung beam at the Cornell synchrotron. The resulting film was scanned for three-prong events; in addition to 310 examples of the single-meson production reaction $\gamma+d\rightarrow\pi^-+p+p$,[1] 135 events were observed which were attributed to the double-meson production reactions $\gamma+d\rightarrow\pi^0+\pi^-+p+p$ and $\gamma+d\rightarrow\pi^+\pi^-+p+n$. If these processes are then interpreted, on the basis of the spectator model, as production of pairs of mesons from the neutron or from the proton, it is concluded that the three reactions $\gamma+n\rightarrow\pi^0+\pi^-+p$, $\gamma+n\rightarrow\pi^+\pi^-+n$ and $\gamma+p\rightarrow\pi^+\pi^-+p$ occur in deuterium with comparable frequencies and with total cross-sections of the same order of magnitude as that for the reaction $\gamma+p\rightarrow\pi^+\pi^-+p$ for free protons.[2]

* Work supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] D. H. White (to be published).
[2] J. M. Sellen, G. Cocconi, V. T. Cocconi, and E. L. Hart, Phys. Rev **113** 1323 (1959).

**EA2. Peripheral Pion Production of Low Multiplicity in $\pi^-$-Proton Collisions at High Energy.†** F. SALZMAN, *University of Colorado.*—The large asymmetry found in single pion production[1,2] at 5 Bev $\pi^-$-proton collisions may be explained[1] by a direct collision of the incoming $\pi^-$ and a meson in the nucleon cloud. However, there is an analogous process for double $\pi$-production in which the nucleon is left in an excited state and decays via the 3-3 resonance.[3] At this energy, both processes can occur for very low 4-momentum, $\Delta^2$, of the virtual pion. For a given $\Delta^2$ and $V$, the total energy of the *di-pi* system in its center of mass, the ratio, $R$, of the total probality for producing the isobar state plus the *di-pi* to the probality of producing just the *di-pi*, is independent of the as yet unknown $\pi$-$\pi$ vertex. For $\Delta^2\approx u^2$ and $V\approx 3u$, $R$ is greater than one for both charge states of the virtual pion. Further consequences of this model will be presented.

† Supported in part by the National Science Foundation.
[1] W. D. Walker, Phys. Rev. **108**, 872 (1957).
[2] G. Maenchen, W. B. Fowler, W. M. Powell, and R. W. Wright, Phys. Rev. **108**, 850 (1957).
[3] V. S. Barašenkov, Nuovo cimento **14**, 656 (1959).

**EA3. Photoproduction of $\pi^+$ from Hydrogen at Small Angles at Energies 700 to 1025 Mev.*** J. H. BOYDEN AND R. L. WALKER, *California Institute of Technology.*—Measurements of the cross section for photoproduction of $\pi^+$ mesons from hydrogen have been extended to angles as small as 5° in the c.m. system. At a photon energy 1025 Mev, the cross section decreases as the angle changes from 5° to 13°, reaching a minimum before increasing again to the maximum near 40° which has been previously observed.[1] Less extensive measurements at energies 700, 800, 900, and 960 Mev all show a similar rapid decrease with angle in the angular range less than 15° c.m., although below 960 Mev no actual minimum is observed. These effects at small angles arise presumably from the "retardation term," or "meson current" term and its interference with other contributions to the photoproduction amplitude. It is interesting that a minimum near 15° is characteristic of the pure Born approximation (retardation term plus "$S$ wave") and a careful analysis will be necessary to identify effects due specifically to the higher resonant states.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] F. P. Dixon and R. L. Walker, Phys. Rev. Letters **1**, 458 (1958).

**EA4. Structure of the Deuteron from Coherent $\pi^0$ Photoproduction.*** J. I. FRIEDMAN AND H. W. KENDALL, *Stanford University.*—Coherent photoproduction of $\pi^0$ mesons from deuterium is sensitive to the structure of the deuteron and consequently can be used to measure the deuteron form factor. Absolute measurements of the production cross section have been completed for photon energies from 470 to 510 Mev by detecting momentum-analyzed recoil deuterons. The

deuteron form factor has been determined in the range of momentum transfers from 1.75 to 2.75 fermi$^{-1}$. An impluse approximation calculation, including only the deuteron $S$ state, gives a structure form factor consistent with the predictions of a repulsive core potential. There is a large reduction of the production cross section for photon energies near the 3,3 production resonance with respect to the impulse approximation prediction. This is in qualitative agreement with calculated corrections arising from multiple scattering of the meson in the deuteron.[1] Theoretical analysis now in progress will allow a more complete interpretation of the experiment.

* Supported in part by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Force Office of Scientific Research.
[1] J. Chappelear, Phys. Rev. 99, 254 (1955).

**EA5. Photoproduction of Pion Pairs from Hydrogen.*** S. RICHERT AND A. SILVERMAN, *Cornell University.*—We are studying the reactions $\gamma+p\rightarrow\pi^+ +\pi^- +p$ and $\gamma+p\rightarrow\pi^0 +\pi^0 +p$. It is hoped that the ratio of the cross sections for these two reactions will provide information about possible pion-pion interactions in the final state. The recoil proton is detected in coincidence with one of the charged pions or one $\gamma$ ray from the decay of a neutral pion. The bremsstrahlung beam of peak energy up to 1250 Mev is passed through a liquid hydrogen target, and protons produced at a laboratory angle of 25° and momentum 600 Mev/$c$ are focused by a magnetic spectrometer into a scintillation counter telescope where they are detected, with pulse height discrimination to exclude pions and electrons. Pions and $\gamma$ rays are detected at a laboratory angle of 25° by a three-counter telescope with lead converter between the first and second counters. Thus charged pions register in all three counters, $\gamma$ rays in only the second and third counters. We plan also to detect the $\gamma$ rays with a total absorption Čerenkov counter so that their spectrum can be determined. Adequate precautions are taken to keep the background from single pion production negligible. Preliminary results indicate that the yield of neutral pion pairs is substantially lower than that of charged pairs.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**EA6. Photopion Production from Deuterium and the $\pi^-/\pi^+$ Ratio.*** WILLIAM P. SWANSON, JOHN D. ANDERSON, DUANE C. GATES, THOMAS L. JENKINS, AND ROBERT W. KENNEY, *Lawrence Radiation Laboratory, Berkeley.*—The reactions $\gamma+D\rightarrow\pi^- +2P$ and $\gamma+D\rightarrow\pi^+ +2n$ are being studied near threshold by observing 2- and 3-prong stars and $\pi^+\rightarrow\mu^+ +\nu$ decays, respectively, in a 4-in. deuterium bubble chamber, as previously reported.[1] To date 422 $\pi^-$ and 391 $\pi^+$ events have been analyzed. Their average laboratory energy was 6.4±2.7 Mev and their angular distributions were isotropic within statistics. The ratio $\pi^-/\pi^+=1.40\pm0.12$ is corrected for chamber efficiency only. A calculated final-state coulomb correction reduces the ratio to $\pi^-/\pi^+=1.26\pm0.11$. Further results will be presented, along with an angular distribution of the $\pi^-/\pi^+$ ratio, an analysis of the $\pi^- +2P$ final state, and negative photopion production cross sections on free neutrons obtained by means of a Chew-Low type extrapolation. The help of D. A. McPherson with the bubble chamber is gratefully acknowledged.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] J. D. Anderson, D. C. Gates, T. L. Jenkins, R. W. Kenney, and W. P. Swanson, Bull. Am. Phys. Soc. Ser. II, 4, 274 (1959).
[2] G. F. Chew and F. E. Low, Phys. Rev. 113, 1640 (1958).

**EA7. Photoproduction of Single Negative Mesons in Deuterium.*** D. H. WHITE, B. M. CHASAN, G. COCCONI, V. T. COCCONI, AND R. M. SCHECTMAN, *Cornell University.*—A 1040-Mev bremsstrahlung beam from the Cornell synchrotron has been passed through a deuterium filled diffusion cloud chamber. A total of 310 examples of the reaction $\gamma+d\rightarrow p+p+\pi^-$ have been observed from threshold to 1 Bev. The total cross section for the reaction $\gamma+n\rightarrow p+\pi^-$ has been evaluated with the aid of the "spectator model" and is in good agreement with results of the minus-plus meson ratio together with the cross section for the reaction $\gamma+p\rightarrow n+\pi^+$. The momentum distribution of spectator protons agrees well with the internal momentum distribution as calculated from the deuteron wave function, verifying the validity of the spectator model. Evidence bearing on the presence of final state interactions will be discussed.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**EA8.** (Abstract withdrawn).

**EA9. $\pi^-$-$P$ Scattering at 150 Mev.*** W. P. KOVACIK, J. ASHKIN, S. KELLMAN, AND T. A. ROMANOWSKI, *Carnegie Institute of Technology.*—The differential elastic and total cross sections for 150-Mev negative pions on hydrogen have been measured. An analysis of the incident pion beam from the synchocyclotron was made with a Čerenkov counter which yielded an 11%±2% contamination of negative muons and electrons. In order to detect only elastically scattered pions, a proton recoil counter in coincidence with the scattering leg counters was used for the backward angles. For the remaining angles a Čerenkov counter was used to separate pions from the electrons which comprised up to 20% of the particles in the scattering leg. The total cross section was measured to be tentatively 63.0±1.5 mb. The differential cross section will be presented.

* Supported in part by the U. S. Atomic Energy Commission.

**EA10. $\pi^-$ Scattering from Complex Nuclei.*** R. M. EDELSTEIN, W. F. BAKER,† AND J. RAINWATER, *Columbia University.*—Differential cross sections were measured for $\pi^-$-carbon scattering at 69.5 Mev and 87.5 Mev and $\pi^-$-oxygen scattering at 87.5 Mev from 20° to 125°, extending the technique of Baker *et al.*[1] Elastic and 5- and 10-Mev inelastic cross sections were obtained. The energy resolution was sufficient to measure pure elastic cross sections. The modified Kisslinger optical model equation program of Baker *et al.*[2] was used to fit the elastic cross section data. A $\chi^2$ analysis for the 69.5-Mev carbon data gave a nuclear radius parameter, $r_0=1.05\pm0.03$ fermis and a falloff parameter $t=1.25\pm0.07$ fermis. These parameters give good fits to the other data as well. An energy dependence in the strength parameters for carbon is observed in qualitative agreement with prediction. A modification to the equation by Kroll[3] does not give as close a fit to the data.

* Research supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Present address: Brookhaven National Laboratory.
[1] W. F. Baker, J. Rainwater, and R. E. Williams, Phys. Rev. 112, 1763 (1958).
[2] W. F. Baker, H. Byfield, and J. Rainwater, Phys. Rev. 112, 1773 (1958).
[3] N. M. Kroll (unpublished).

**EA11. Charge-Exchange Scattering of Negative Pions by Hydrogen at 230 and 290 Mev.*** JOHN C. CARIS, ROBERT W. KENNEY, VICTOR PEREZ- MENDEZ, AND WALTON A. PERKINS, III., *Lawrence Radiation Laboratory, Berkeley.*—The differential cross section for charge-exchange scattering of negative pions by hydrogen has been observed at nine laboratory-system angles for incident pion energies of 230±8 and 290±9 Mev. The reaction was observed by detecting one gamma ray from the $\pi^0$ decay with a scintillation-counter telescope. A least-squares analysis was carried out to fit the observations to the function $d\sigma/d\omega=\Sigma_l a_l P_l(\cos\theta)$, in the c.m. system. The preliminary results, in units of mb, are

| Energy | $a_0$ | $a_1$ | $a_2$ |
|---|---|---|---|
| 230±8 | 2.45±0.10 | 1.49±0.17 | 2.95±0.33 |
| 290±9 | 1.45±0.06 | 1.77±0.10 | 1.91±0.18 |

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**EA12. Mean Life of the Positive Pion.** J. ASHKIN, T. FAZZINI, G. FIDECARO, Y. GOLDSCHMIDT-CLERMONT, N. H. LIPMAN, A. W. MERRISON, AND H. PAUL, *CERN, Geneva.*—Positive pions produced by the CERN synchro-cyclotron were stopped in a scintillation counter. The shaped pulses were displayed on a fast oscilloscope whose useful sweep length was 13-pion mean lives so that practically all decay muons were visible unless they came within 3.7 mμsec after the pion pulse. The pulses were recorded on film, and their heights and time separations were measured on an instrument designed for the evaluation of bubble chamber pictures. The data were checked for consistency and analysed on a fast electronic computer. The background, i.e., $\pi$-$\mu$-$e$ decays where the muon came within 3.7 mμsec of the pion, was reduced by subjecting the muons to a height criterion. From a histogram of measured decay times, the mean life was derived both by a least squares fit and by a maximum likelihood method; the results agreed. Accepting all decay times >16 mμsec, we obtained the mean life 25.46±0.32 mμsec. This value is based on 8307 decays of which 136±18 are background. It agrees well with previous measurements by other groups.

**EA13. Auger Electrons from Stopped $\pi^-$ Stars.*** A. G. BARKOW AND J. CUEVAS, *Marquette University,* G. KANE, *Manhattan College,* R. E. MCDANIEL, *New Mexico State College* AND Z. O'FRIEL, *St. Bonaventure University.*—A preliminary report on the analysis of 3000-stopped $\pi^-$ stars having an Auger electron associated with the sigma star. The frequency of $\sigma$ stars having one Auger electron is one in ten; for two Auger electrons, it is one in two thousand; and for three Auger electrons, it is one in a thousand. Ninety percent of the electrons originate from heavy nuclei, with the majority being associated with zero, one, and two prong stars. Angular distribution data indicates an isotropic emission. Energy distribution of the Auger electrons from heavy and light nuclei will be given.

* Work supported by the National Science Foundation.

**EA14. New Particles and Resonances Predicted by the Relativistic Rotator Model for Mesons and Hyperons.** ERNEST J. STERNGLASS, *Westinghouse Research Laboratories.*—The semi-classical hyperon model involving an electron of relativistic mass $137m_0$ circulating around a proton in an orbit of radius $r\simeq(\frac{1}{2})e^2/m_0c^2$ possesses a series of excited rotational states which should appear either as particles or resonances in high-energy scattering experiments.[1] It will be shown that the resonances in $(\pi,p)$ and $(\gamma,p)$ scattering recently observed agree with those of the model, both as to their location and angular momentum assignment. Taken together with the states represented by known particles, it is found that there now exists experimental evidence for every excited state in the energy range investigated. This makes it possible to predict the location and angular momenta of $(\gamma,p)$ and $(\pi,p)$ resonances in the energy range beyond 1 Bev now becoming accessible. Since the model permits a simple physical interpretation of strangeness and isotopic spin selection rules, it also provides a basis for predicting the masses, strangeness, production thresholds, and decay modes of new mesons and hyperons which should be observed as the available energies are increased. The new particles of lowest threshold predicted are a pseudo-scalar meson of strangeness $S=2$, mass $2192m_0$, $(\gamma,p)$ threshold 2.7 Bev and a hyperon of $S=-2$, mass $3001m_0$, $(\gamma,p)$ threshold 2.9 Bev. No other new mesons or hyperons should be produced up to $\gamma$-ray energies of 5.3 Bev, the threshold for a hyperon of $S=-3$ and mass $3549m_0$.

[1] E. J. Sternglass, Bull. Am. Phys. Soc. Ser. II, 4, 228 (1959).

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## MONDAY AFTERNOON AT 2:00

## Adams-Hamilton Room

## (W. F. HORNYAK presiding)

## *Helicity; Radioactive Nuclei, I*

**F1. Mott Scattering Asymmetry by Foils of Finite Thickness.** HORST WEGENER, *Oak Ridge National Laboratory* (introduced by H. B. Willard).—Transversely polarized electrons can be scattered by a thin foil (Mott scattering). The resultant left-right-asymmetry $(PS)_t$ depends upon the degree of polarization $P$, Sherman's function $S$, and the foil thickness $t$. Single scattering is always accompanied by plural and small angle scattering. If one expands the asymmetry in terms of the foil thickness $(PS)_t=(PS)_0+(PS)_1t+\cdots$, one gets the desired single scattering term $(PS)_0$, the influence of small angle and double scattering $(PS)_1t$, etc. The double scattering term diverges logarithmically, if either one of the two scattering angles goes to zero, or if the first scattering occurs in a direction perpendicular to the normal of the foil. Both divergences vanish after applying the Bothe-Fermi Theory of small angle scattering to these regions. The straightforward calculations were done by the ORACLE computer. A comparison of the results with more approximate calculations[1] shows that the latter underestimated the double scattering in the regions between the divergences. The ORACLE results agree well with experimental data of the Mott scattering groups in Oak Ridge and Erlangen.

[1] H. Wegener, Z. Physik 151, 252 (1958).

**F2. $\beta$-$\gamma$ Circular Polarization Correlation of $Sb^{124}$.*** G. HARTWIG AND H. SCHOPPER, *University of Mainz.*—The first forbidden $3^-\rightarrow 2^+$ $\beta$ decay of $Sb^{122}$ shows considerable deviations from an allowed shape and a large $\beta$-$\gamma$-anisotropy. This

cannot be explained by a "cancellation effect" as in the case of RaE. The measurement of the $\beta$-$\gamma$-circular polarization correlation permits to determine the matrix elements uniquely. The circular polarization of the $\gamma$-rays determined by Compton scattering from magnetized iron was found to be $P_\gamma = -0.107 \pm 0.03$ and $+0.226 \pm 0.04$ for the two angles $\theta = 160°$ and 126°, respectively, at an average electron energy of 1.7 Mev. From these results and the $\beta$-$\gamma$-anisotropy[1] the following matrix elements (given in the notation of Kotani[2]) can be deduced: $Y = 0.42 \pm 0.1$, $u = -0.01 \pm 0.02$ and $x = 0.05 \pm 0.05$. This set is in agreement with the "modified $B_{ij}$ approximation."[3] Thus $Sb^{122}$ is the first well-established example of the "selection rule effect."[3,4] In addition information on the size of relativistic matrix elements were obtained.

* Supported by Bundesministerium für Atomkernenergie und Wasserwirtschaft.
[1] R. M. Steffen (private communication).
[2] T. Kotani, Phys. Rev. 112, 795 (1958).
[3] Matumoto, Morita and Yamada, Bull. Kobayasi Inst. Phys. Research 5, 210 (1955).
[4] M. Morita and R. S. Morita, Phys. Rev. 109, 2048 (1958).

**F3. Circular Polarization of Internal Bremsstrahlung Accompanying $\beta$ Decay.*** S. GALSTER AND H. SCHOPPER, *University of Mainz.*—The polarization of internal bremsstrahlung was measured by Compton scattering from magnetized iron as a function of quantum energy. The decays of $P^{32}$ (allowed), RaE (first forbidden), and $Y^{90}$ (unique forbidden) were investigated. All necessary corrections were carefully determined. The polarization of $P^{32}$ is in good agreement with theory proving that the violation of parity conservation can be detected also in second-order processes. The results for RaE are lower than those expected for an allowed transition by a factor of $0.61 \pm 0.07$ (averaged over photon energy). This ratio is somewhat smaller than the corresponding value for the electron polarization. The polarization of $Y^{90}$ is in agreement with the expectation for an allowed transition. As the theory for forbidden transitions has not yet been developed a complete understanding of this result is not possible at present.

* Supported by Bundesministerium für Atomkernenergie und Wasserwirtschaft.

**F4. Lifetimes of the First Excited States of $F^{17}$ and $O^{17}$.*** J. V. KANE, R. E. PIXLEY, R. B. SCHWARTZ, AND A. SCHWARZCHILD, *Brookhaven National Laboratory.*—Using the gamma-gamma coincidence method and 6BN6 time-to-amplitude converter circuitry similar to that described by Green and Bell,[1] we have measured the lifetimes of the first excited states in the mirror pair, $O^{17}$ (0.87 Mev) and $F^{17}$ (0.59 Mev). The reactions initiating the gamma cascades were $O^{16}(d,p)O^{17}$, leading to the 3.1-Mev $O^{17}$ state, and $O^{16}(p,\gamma)F^{17}$, leading to $F^{17}$ at 2 Mev in the continuum. One RCA type 7264 and one Amperex type 56AVP were used, with 1 in. long$\times 1\frac{1}{2}$ in. diam plastic scintillators. For the measured radiations prompt coincidence spectra were obtained with half-widths $< 5 \times 10^{-10}$ sec, and exponential slopes which decreased a factor of two in $< 9 \times 10^{-11}$ sec. It was therefore possible to determine the state lifetimes by analysis of the exponential decay, rather than by observing centroid shifts. The measured mean-life of $O^{17*}$ is $(2.55 \pm 0.13) \times 10^{-10}$ sec; the measured mean-life of $F^{17*}$ is $(4.45 \pm 0.22) \times 10^{-10}$ sec. While our measured $O^{17*}$ lifetime is in good agreement with an earlier result,[2] our $F^{17*}$ lifetime is larger than the previously accepted value.

* Research supported by the U. S. Atomic Energy Commission.
[1] R. E. Green and R. E. Bell, Nuclear Instr. 3, 127 (1958).
[2] J. Thirion and V. L. Telegdi, Phys. Rev. 92, 1253 (1953).

**F5. Longitudinal Polarization of $O^{14}$ Positrons.*** J. C. HOPKINS, J. B. GERHART, F. H. SCHMIDT, AND J. E. STROTH, *University of Washington.*—The longitudinal polarization of positrons from $O^{14}$ has been measured using Bhabha scattering. Preliminary analysis of data yields $(+0.98 \pm 0.16)$ $v/c$ for the longitudinal polarization. A previous investigation of the circular polarization of annihilation-in-flight photons yielded $(+0.73 \pm 0.17)$ $v/c$ for this polarization.[1] The spectrometer and gas system of the previous experiment were used to provide 1-Mev positrons. A solenoidal magnetic lens focused the positrons on a 0.0002-in. supermendur foil magnetized by the lens. The magnetic field could be reversed, thus reversing the magnetization of the foil, without disturbing the focusing properties of the lens. The scattered particles were detected in plastic scintillators coupled to RCA 6810A photomultipliers. A fast-slow coincidence circuit ($2\tau \sim 5 \times 10^{-9}$ sec) detected the Bhabha scattered particles. These coincidence counts were normalized by an on-axis positron monitor. Corrections were made for instrumental asymmetries and slow coincidence counts arising from sources other than Bhabha scattering in the foil.

* Supported in part by the U. S. Atomic Energy Commission.
[1] J. B. Gerhart, F. H. Schmidt, H. Bichsel, and J. C. Hopkins, Phys. Rev. 114, 1095 (1959).

**F6. Circular Polarization of $\gamma$ Rays Following Capture of Polarized Neutrons in $S^{32}$ and $Y^{89}$.** J. VERVIER,* *Chalk River Laboratories* (introduced by J. M. Robson).—The circular polarization of $\gamma$ rays following the capture of polarized thermal neutrons in $S^{32}$ and $Y^{89}$ has been studied using the polarized neutron beam at the NRU reactor. The circular polarization of the capture $\gamma$ rays is measured by transmission through magnetized iron. The following limits, with conservative errors, have been obtained for the ratio $R$ between the capture $\gamma$-ray circular polarization and the component of the neutron polarization along the $\gamma$-ray direction[1]: for the 5.44-Mev capture $\gamma$ ray in $S^{33}$, $-0.882 < R < -0.141$; for the 6.07-Mev capture $\gamma$ ray in $Y^{90}$, $-1.376 < R < -0.244$. The result on $S^{33}$ is consistent with the known spin and parity $(\frac{3}{2}-)$ of the 3.22-Mev level in $S^{33}$ and agrees with a previous measurement using the same method.[1] The result on $Y^{90}$ shows that the spins of the capturing state and of the 0.7777-Mev level in $Y^{90}$ are 1 and 2, respectively, as suggested by angular correlation measurements.[2]

* Seconded from C.E.N., Mol, Belgium.
[1] G. Trumpy, Nuclear Phys. 2, 644 (1957).
[2] G. Bartholomew *et al.*, Nuclear Phys. 10, 590 (1959).

**F7. Bremsstrahlung Excitation of Nuclear Resonance Fluorescence.*** E. C. BOOTH, *Boston University.*—Nuclear resonance fluorescence has been observed using the bremsstrahlung produced by a 3 Mev Van de Graaf electron accelerator. The resonance radiation is ring scattered and counted at 100° by a crystal shielded from the direct beam. The large background is subtracted by using dummy scattering rings. For low $Z$ and high abundance, lifetimes less than about $10^{-12}$ sec can be measured in the region 0.7 to 2.0 Mev with a 50% error by absolute measurements. More accurate measurements using the absorption method and a multichannel analyzer will be made. Although restricted to short lifetimes, the method is comparatively simple and rapid. The results are shown below, where $g$ is the statistical factor $1+2I+2I_0$. Previously measured values are in parentheses.

| | | | | |
|---|---|---|---|---|
| $Cu^{63}$ | 0.67 Mev | $2.4 \times 10^{-13}$ | $(3 \times 10^{-13})$ | $g = 0.5$ |
| $Cu^{65}$ | 0.96 Mev | $3.8 \times 10^{-13}$ | $(4 \times 10^{-13})$ | $g = 1.5$ (?) |
| $Cu^{65}$ | 0.77 Mev | $4.7 \times 10^{-13} g$ | | |
| $P^{31}$ | 1.26 Mev | $3.3 \times 10^{-13}$ | | $g = 2$ |

* Supported by the National Science Foundation.

**F8. Half-Lives of Some Nuclear Energy States in the $\mu$sec Region.*** T. D. NAINAN, *Indiana University.*—By using a fast time to amplitude converter[1] in connection with a 100-channel pulse height analyzer, the lifetimes of several short lived nuclear states have been measured. The

apparatus uses single channel pulse height analyzers in each gamma-ray branch. The results fall into two classes: (a) Half-lives on which there is disagreement between several investigators or which have only been measured by delayed coincidence techniques; (b) new results. Under (a) the values are as follows: 124-kev state of $Cs^{131}$, $4.10\pm0.05\times10^{-9}$ sec; 323-kev level of $V^{51}$, $0.29\pm0.04\times10^{-9}$ sec; 123-kev level of $Gd^{154}$, $1.14\times10^{-9}$ sec. (b) New results: 555-kev level of $Mn^{52}$, $1.85\pm0.05\times10^{-9}$ sec; 155-kev level of $Sb^{119}$ (from $Te^{119}$), $0.84\pm0.05\times10^{-9}$ sec.

* Supported by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. E. Green and R. E. Bell, Nuclear Instr. 3, 127 (1958).

**F9. Beta Ray Produced Photon Yields from Cl-36 Distributed in a Multi-Element Matrix.** WILLARD D. CHEEK AND FARNO L. GREEN, *General Motors Research Laboratories.*—Experimental values of beta ray excited yields of bremsstrahlung and characteristic x-rays in multi-element radiators are needed for better understanding of the spectral emission of photons from thick sources of some beta decaying radioisotopes. A radioactive source which illustrates the problem is $Sm^{153}$ uniformly distributed in a matrix composed of equal weights of $Sm_2O_3$ and Al. The beta-excited photon spectrum of such a source cannot be studied directly because of the presence of superimposed gamma rays and x-rays from internal conversion. To avoid these interferences the beta emitter $Cl^{36}$, which is free of gamma rays, was substituted for $Sm^{153}$. The $Cl^{36}$, as NaCl, was mixed with appropriate amounts of $Sm_2O_3$ and Al to simulate the $Sm^{153}$ source composition. Experimental pulse-height distribution curves of the photon yields were obtained as a function of source thickness using a 100-channel NaI(Tl) scintillation spectrometer. Maximum photon production in the Sm $K$ x-ray region was obtained at a source thickness of $\sim$200 mg/cm$^2$. At this thickness the following approximate yields in photons per disintegration were obtained: (15–32 kev): 0.003 due to bremsstrahlung, (32–48 kev): 0.003 due to bremsstrahlung, and 0.002 due to Sm $K$ x-ray production, and (48–200 kev): 0.005 due to bremsstrahlung.

**F10. Coincidence Studies of Iron Capture Gamma Rays.*** R. E. SEGEL, *Wright Air Development Center, Wright-Patterson Air Force Base,* AND W. R. KANE, *Brookhaven National Laboratory.*—The gamma-ray decay of $Fe^{57}$ following thermal neutron capture in $Fe^{56}$ has been investigated with the aid of coincidence measurements between a three-crystal pair spectrometer and a single NaI crystal. The decay of the 0.365-Mev state is predominantly to the first excited state, in accord with Coulomb excitation results[1] and studies of radioactive decay.[2] The existence of a strong transition to this level from the $\frac{1}{2}+$ state formed in thermal neutron capture casts doubt on a previously suggested $\frac{5}{2}-$ assignment.[1] A search for an electron capture transition from $Co^{57}$ to this state yielded negative results (log ft$>$9.3). Evidence will be presented to show that a $\frac{3}{2}-$ assignment from the 0.365-Mev state best fits all available data. The 1.63- and 1.73-Mev states in $Fe^{57}$ were each found to de-excite by transitions to the ground state doublet of levels (unresolved) in roughly half of all decays.

* Work performed under the auspices of U. S. Air Force and U. S. Atomic Energy Commission.
[1] G. F. Pieper and N. P. Heydenburg, Phys. Rev. **107**, 1300 (1957).
[2] H. R. Lemmer, O. J. A. Segaert, and M. A. Grace, Proc. Phys. Soc. (London) **A68**, (1955).

**F11. Decay Energy of $Y^{88}$.*** P. S. JASTRAM AND M. K. RAMASWAMY, *The Ohio State University.*—Although the gamma-spectrum following the decay of 105-day $Y^{88}$ is well known, the end-point of the weak positron spectrum leading to the 1.86-Mev level in $Sr^{88}$ is fixed with far less certainty; this in turn introduces uncertainty in the total energy available for the $Y^{88}$-$Sr^{88}$ decay. We have obtained an approximate value for the decay energy by determining the $L/K$ ratio for the capture transition to the 2.76-Mev level in $Sr^{88}$. From a measurement of the $K$ x-rays in coincidence with the 0.900-Mev gamma ray, the decay energy is estimated to be $540\pm160$ kev. This leads to a value of $420\pm160$ kev for the end-point of the positron spectrum. A direct determination of the end-point is being made by measuring the positrons in coincidence with the 1.86-Mev gamma ray and annihilation radiation. This procedure eliminates the effects of the internal pair positron spectrum from the 1.86-Mev gamma ray, which had caused difficulties in earlier measurements.[1]

* Supported by the U. S. Atomic Energy Commission.
[1] W. L. Stirling and N. Goldberg, Bull. Am. Phys. Soc. Ser. II, 1, 291 (1956).

**F12. Energy Levels of Ruthenium-99 Deduced from the Decay of Two Isomers, 16.1 Day and 4.6 Hour, of Rhodium-99.*** J. D. KURBATOV, C. W. TOWNLEY,† B. FEIGLEY, AND M. H. KURBATOV, *The Ohio State University.*—The following energy levels were obtained as a result of gamma-gamma coincidence studies of the decay of two isomers; 90, 319, 340, 439, 615, and 630 kev. Less populated levels which have an element of uncertainty because of the large number of gamma rays with energy values close together are, 708, 853, 903, 1035, 1235, 1285, 1355, 1398, 1605, 1745, and 1875 kev. Carrier free rhodium-99 was separated from proton activated enriched ruthenium-99.[1] A crystal scintillation spectrometer was used. The internal conversion electrons of the 16.1-day isomer were investigated in a thick lens magnetic spectrometer. The $K/(L+M)$ ratio was obtained for the stronger groups of Monochromatic electrons corresponding to the following deexcitations; 90, 175, 349, and 525 kev. Independent verification of the more intense gamma rays was made by study of the external conversion electrons in a magnetic spectrometer. Energy level diagram and gamma rays observed will be presented.

* Work performed under the auspices of a U. S. Atomic Energy Commission contract.
† Present connection: Battelle Memorial Institute, Columbus, Ohio.
[1] Activation was made in the cyclotron of the University of Washington, Seattle, Washington. The cooperation of T. J. Morgan and G. W. Farwell is gratefully acknowledged.

**F13. Decay of $Ag^{104}$.** H. NUTLEY AND J. B. GERHART, *University of Washington.**—The decay of $Ag^{104}$ has been investigated. $Ag^{104}$ was produced by alpha particle bombardment (33 to 42 Mev) of rhodium foil; chemical identification was performed. The spin 5 isomer decays with half life $66\pm1$ minutes, the spin 2 isomer with half-life $29.8\pm0.5$ minutes. Conversion electrons corresponding to gamma rays of 167, 262, 282, 355, 443, 478, 556, 621, 767, 854, 938, 1026, 1074, 1263, 1343, 1529, 1623, and 1806 kev were observed; no conversion electrons corresponding to a previously reported[1] 745-kev gamma ray were observed. The 556, 767, and 938-kev gamma rays were found to be in cascade by fast coincidence. The spin 2 isomer decays by positron emission with end-point energy $2.705\pm0.015$ Mev and allowed shape spectrum. No 1.9 Mev positrons, as previously reported, are observed.[1] Positrons from the spin 2 isomer were found to be in fast coincidence with the 556-kev gamma rays. Previously unreported positrons from the 5+ isomer were observed having an allowed shape and an end point energy of $990\pm10$ kev. The $Pd^{104}$ level scheme will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. K. Girgis and R. Van Lieshout, Nuclear Phys. 13, 493 (1959).

MONDAY AFTERNOON AT 2:00

Franklin Room

(WALTER GORDY presiding)

## *Molecules II: Nuclear Magnetic Resonance*

**FA1. Hyperfine Splitting of $3_2 \rightarrow 3_3$ Transition of HDO.*** E. B. TREACY AND YARDLEY BEERS, *New York University.*—The observation of low-frequency transitions presents the opportunity to resolve very small hyperfine splittings with an absorption method provided that the cell is large enough to eliminate wall collisions because the Doppler width decreases with the frequency while the hyperfine splitting bears no systemmatic dependence on frequency. Using cavity spectrometer driven by a parametric up converter and followed by a superhetrodyne receiver, we have studied the $3_2 \rightarrow 3_3$ line of HDO at 825 Mc. The minimum full line width at half maximum is 10 kc. Seven satellites have been well resolved on each side of the main line, and their frequencies are being measured. These data will be analyzed for determination of the deuteron quadrupole coupling constant and the $I \cdot J$ coefficients for comparison with the recent maser observation of the $2_1 \rightarrow 2_2$ line by Thaddeus and Loubser.[1]

* Supported by the Electronics Branch of the Office of Naval Research and the Air Force Office of Scientific Research.
[1] P. Thaddeus and J. Loubser, Nuovo cimento **13**, 1060 (1959).

**FA2. Millimeter and Submillimeter Wave Spectroscopy: Evaluation of Centrifugal Distortion Effects in BrCN and $NF_3$.*** MONROE COWAN AND WALTER GORDY, *Duke University.*—Submillimeter wave transitions in $Br^{81}CN$ were measured at 392 907.0±0.9 Mc/sec ($J=47\rightarrow48$), at 425 575.9±0.9 Mc/sec ($J=51\rightarrow52$), and at 458 226.2±0.9 Mc/sec ($J=55\rightarrow56$). These, with the millimeter wave transitions measured earlier,[1] were found to fit the frequency equation,

$$\nu = 2B(J+1) - 4D(J+1)^3 + 2H(J+1)^3(2J^2+6J+4),$$

with the values: $B=5096.808$ Mc/sec, $D=8.716\times10^{-4}$ Mc/sec, and $H=-7\times10^{-10}$ Mc/sec. So far as we know, this represents the first measurement of the higher order stretching constant $H$ in microwave spectroscopy. Less accurate measurements have been made on transitions of BrCN up to 589 kMc/sec or 0.509-mm wavelength. From measurements of transitions of $NF_3$ in the shorter millimeter wave region the values: $B_0=10\,680.45$ Mc/sec, $D_J+0.0095$ Mc/sec, $D_{JK}=-0.022$ Mc/sec, and $eQq$ ($N^{14}$) $=-7.09$ Mc/sec. The values of $D_J$ and $D_{JK}$ differ significantly from the earlier rough values obtained from lower $J$ transitions[2] but agree well with values estimated by Schatz[3] from vibrational force constants.

* Supported by the Office of Scientific Research, U. S. Air Force.
[1] C. A. Burrus and W. Gordy, Phys. Rev. **101**, 599 (1956).
[2] C. M. Johnson, R. Trambarulo, and W. Gordy, Phys. Rev. **84**, 1178 (1951); P. N. Schatz, J. Chem. Phys. **29**, 481 (1958).

**FA3. Centrifugal Distortion and Vibration-Rotation Effects in Asymmetric Rotors.*** JOHN G. BAKER, *Duke University* (introduced by W. Gordy).—The following formula is shown to describe centrifugal distortion in the rotational energy levels of any asymmetric top molecule with high accuracy:

$$\begin{aligned}\Delta W_{\text{cent}} = &-(D_J+\tfrac{1}{2}bR_{10})J^2(J+1)^2 \\ &-(D_{JK}-bR_{10})J(J+1)\left(w-b\frac{dw}{db}\right) \\ &+2\delta_J J(J+1)\frac{dw}{db}-(D_K+\tfrac{1}{2}bR_{10})\left(w^2-bw\frac{dw}{db}\right) \\ &+R_{10}w\frac{dw}{db}+\text{standard correction terms in }(R_b+\tfrac{1}{2}bR_{10})\end{aligned}$$

$w$ is the conventional "reduced energy" taking the value of $K^2$ in the symmetric top limit, and $b$ the Wang asymmetry parameter.[1] All other constants have been defined by Nielsen[2] with the exception of $R_{10}$, which has the value $(bD_K+4R_b)/(1-\frac{1}{2}b^2)$. This formula has been applied to the millimeter wave spectra of formyl fluoride and formic acid and the constants obtained used to estimate the inertial shifts due to zero point vibration and to obtain better values for the molecular parameters.

* This work was supported by the Air Force Office of Scientific Research.
[1] See, for example, G. W. Robinson, J. Chem. Phys. **27**, 1227 (1957).
[2] H. H. Nielsen, Revs. Modern Phys. **23**, 90 (1951).

**FA4. Variational Calculation of Magnetic Hyperfine Interaction.** T. P. DAS* AND A. MUKHERJEE, *Saha Institute of Nuclear Physics, Calcutta.*—A variational method is proposed for calculation of isotropic magnetic hyperfine constants in paramagnetic atoms and ions with unpaired electrons in $l\neq0$ orbital states and in free radicals. Application is made to the nitrogen atom where $A$ ($N^{14}$) in the term $A\mathbf{I}\cdot\mathbf{S}$ in the Spin-Hamiltonian is calculated to be 7.3 Mc/sec as compared to the recent experimental value of $+10.4509+0.0003$ Mc/sec. The calculated value of $A$ ($N^{14}$) is the sum of two opposing contributions of $-36.4$ Mc/sec and $+43.7$ Mc/sec respectively, from the $1s$ and $2s$ states.

* Present address: Department of Chemistry, Columbia University, New York. Supported by a U. S. Atomic Energy Commission contract.
[1] L. W. Anderson, F. M. Pipkin, and J. C. Baird, Phys. Rev. **116**, 87 (1959).

**FA5. Relation Between the Proton Hyperfine Interaction and the $C^{13}-H^1$ Spin-Spin Coupling in Free Radicals.** R. A. BERNHEIM AND T. P. DAS, *Columbia University.*—It is shown that the $C^{13}-H^1$ spin-spin coupling constant $J(C^{13}-H^1)$ and the proton hyperfine constant $Q(H^1)$ in a free radical can be considered as interdependent, and that they both can be estimated by calculating the perturbation produced in the electronic wave functions by the magnetic moment of the proton. For a C−H fragment with an unpaired $\pi$-electron on the carbon atom an approximate relation is established between $Q(H^1)$ and $J(C^{13}-H^1)$. Using the experimental value of $J(C^{13}-H^1)$ for the benzene molecule, $Q(H^1)$ is found to have a negative sign and order of magnitude agreement with experiment.

**FA6. Molecular Beam Electric Resonance Measurements of the Vibrational Constants of LiF and LiCl.** T. I. MORAN AND J. W. TRISCHKA, *Syracuse University.*—The molecular beam electric resonance method was used to determine the vibrational constants of LiF and LiCl from measurements of the relative intensities of radiofrequency spectra for the two lowest vibrational states of these molecules. Within the limits set by experimental errors, about one percent, the results agreed with the values found from infrared absorption measments.[1,2] It has been concluded from this agreement and other evidence that the efficiency of surface ionization of LiF or LiCl on an oxygenated tungsten wire does not depend on the vibrational state of the molecule, and that the distribution of vibrational states among the molecules effusing from the molecular beam source is the Boltzmann distribution.

[1] G. L. Vidale, Aerophysics Research Memo No. 32, General Electric Company, Philadelphia, Pennsylvania (1959).
[2] W. Klemperer and S. A. Rice, J. Chem. Phys. **26**, 618 (1957).

**FA7. Polarizability of Alkali Atoms.*** G. E. CHAMBERLAIN AND J. C. ZORN, *Yale University.*—By observing the deflection of a collimated beam of neutral atoms in a transverse in-

homogeneous electric field,[1] we have measured the polarizability of the alkali atoms. The results are:

| Element | $\alpha$ (in units of $10^{-24}$ cm$^3$) |
|---|---|
| Lithium | $15 \pm 3.5$ |
| Sodium | $18 \pm 4.0$ |
| Potassium | $29 \pm 6.0$ |
| Rubidium | $29 \pm 6.5$ |
| Cesium | $36 \pm 7.0$ |

Errors in the value of polarizability are largely systematic and arise mainly from uncertain knowledge about the electric field of the deflecting electrodes and about the position of the beam relative to the electrodes. The values for Na and Rb, by the method of atomic beams, are new; the results for Li, K, and Cs agree with those obtained in previous deflection experiments.[2] These experimental values are more accurate and consistently smaller than those estimated from optical measurements.[3]

* This research has been supported in part by the National Aeronautics and Space Administration.

[1] P. Kusch and V. W. Hughes, *Encyclopedia of Physics* (Springer-Verlag, Berlin, 1959), Vol. 37/1, p. 47.
[2] H. Schaeffers and J. Stark, Physik. Z. **35**, 625 (1934).
[3] Landolt-Börnstein, *Zahlenwerte und Funktionen* (Springer-Verlag, Berlin, 1950), Vol. 1/1, p. 401.

**FA8. Calculation of Alkali Polarizabilities.*** J. C. Zorn and Peter R. Fontana, *Yale University.*—The dipole polarizability of alkali atoms in their ground state has been calculated with hydrogen-like state functions, the effective nuclear charge parameter being derived from optical spectra. Both upper and lower limits for the polarizability are approximated from a general sum rule.[1] The mean calculated values are listed below, together with experimental results from atomic beam deflection measurements.[2] The agreement is somewhat better than appears from other recent calculations of atomic polarizability.[3]

| Element | Polarizability $\alpha$ in units of $10^{-24}$ cm$^3$ Theory | Experiment |
|---|---|---|
| Lithium | $21 \pm 3.0$ | $15 \pm 3.5$ |
| Sodium | $16.5 \pm 2.5$ | $18 \pm 4.0$ |
| Potassium | $28 \pm 4.0$ | $29 \pm 6.0$ |
| Rubidium | $29 \pm 4.0$ | $29 \pm 6.5$ |
| Cesium | $36 \pm 5.0$ | $36 \pm 7.0$ |

* This research has been supported in part by the National Aeronautics and Space Administration and by the Office of Naval Research.
[1] A. Dalgarno and J. T. Lewis, Proc. Roy. Soc. (London) *A***233**, 70 (1955); *A***240**, 284 (1957).
[2] G. E. Chamberlain and J. C. Zorn, Bull. Am. Phys. Soc. Ser. II, **5**, 000 (1960), this issue.
[3] A. Dalgarno and A. E. Kingston, Proc. Phys. Soc. (London) **B73**, 455 (1959).

**FA9. Nuclear Magnetic Resonance in Flowing Fluids.** Louis R. Hirschel, *U. S. Naval Ordnance Laboratory.*—Experiment shows that the steady state nuclear magnetic resonance signal for flowing fluids varies from that when the sample is stationary. In general the signal is a function of the time spent by the fluid in the static magnetic field, the time spent in the radio-frequency field, the velocity of fluid flow and the saturation. The signal response when exhibited as a function of velocity shows several interesting features. Furthermore information may be obtained about the spin-lattice relaxation time. An analysis is given using the Bloembergen equations.

**FA10. Proton Resonance Shifts in Alkali Halide Solutions.** B. P. Fabricand, S. Goldberg, and J. R. Johnson, *Columbia University Hudson Laboratories.*—Shifts in the proton resonance in aqueous alkali halide solutions with respect to distilled water have been measured at a fixed frequency of 56.4 Mc/sec at 21°C as a function of salt concentration. Line widths of about 1 cps and shifts down to a couple of cycles per second were obtained with an accuracy of a few tenths of a cycle per second. In each solution only one resonance line was observed. Some of the shifts at a concentration of 3.5 moles salt/1000 grams water ($M$) are as follows: NaCl, $\delta = -1.12$; KCl, $\delta = -1.40$; NaBr, $\delta = -1.56$; KBr, $\delta = -1.61$. The shifts are linear up to about this concentration and then increase in magnitude more slowly. LiCl shows a linear shift to lower field up to $\delta = +0.50$ at 4.5 $M$, at which point the shift increases more slowly until 8 $M$ ($\delta = +0.74$) where it increases more rapidly to $\delta = +2.18$ at saturation. LiBr shows no observable shift until 16 $M$, at which point it increases rapidly to $\delta = \pm 1.74$ at saturation (about 20.5 $M$).

**FA11. Measurement Broadening in Magnetic Resonance; Effect of Modulation Frequency.** Orlo E. Myers, *Convair Scientific Research Laboratory* (introduced by W. C. Erickson).—A spin system is considered for which the Bloch equations[1] are applicable. The general effect of sinusoidal modulation of the longitudinal field on the amplitude and shape of the phase-detected signal fundamental has been obtained by machine computation for those conditions where no simplifying approximations are satisfactory. When the modulation frequency is negligibly small, the effects of saturation and of modulation amplitude are separable; the situation is more complicated at moderate values of rf input, modulation amplitude, and modulation frequency. (Assignment of the ranges of validity of useful approximations is based on mathematical analysis by R. W. Lowen.) The results have been adapted for use in correcting observed derivative peak-to-peak widths for saturation and modulation broadening.

[1] F. Bloch, Phys. Rev. **70**, 460 (1946).

**FA12. Knight Shift in Tantalum Metal.** Lawrence H. Bennett, *National Bureau of Standards*, and J. I. Budnick,* *IBM Watson Laboratory.*—The nuclear magnetic resonance of $Ta^{181}$ has been observed in tantalum metal at 6.092 Mc in a magnetic field of 11 820 gauss. The Knight shift, relative to $KTaO_3$, is 1.1%. The measurements were made at the National Bureau of Standards with a Varian wide line spectrometer at room temperatures. The sample consisted of a stack of foils of tantalum metal prepared by heating in vacuum at 2500 to 2800°C. The interaction between the very large electric quadrupole moment of $Ta^{181}$ and random internal electric field gradients arising from various crystal defects, notably interstitial impurities, is probably the reason that the nuclear magnetic resonance has not been previously observed in the body centered cubic structure of tantalum metal. The use of foils permitted annealing and degassing at higher temperatures than are possible with powdered specimens in which sintering may occur.

* Supported in part by Department of Defense.

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## Monday Afternoon at 2:00

Caribar-Mural Room

(Ugo Fano presiding)

### *Theoretical Physics II: Nuclear Theory*

**G1. Collective Interpretation of Intermediate Shell Model Calculations—I.*** M. K. Banerjee and C. Levinson, *Princeton University.*—In the usual shell model calculation, one uses the harmonic oscillator wave functions for the single particle states and a plausible from the effective interaction between two nucleons, fixed phenomenologically. One mixes only con-

figurations belonging to the same major shell of the harmonic oscillator. It has been shown that the matrix elements of the commonly used form of the central part of the effective interaction between states in the same major shell may be very satisfactorily reproduced by a linear combination of the operator $Q\cdot Q$, introduced by Elliott,[1] $L^2$, the square of the total orbital angular momentum, the sum of the space exchange operators $\Sigma_{i>j} P_{ij}$ and a single particle operator $\Sigma_i l_i^2$. The coefficients in the linear combination depend upon the number of particles and the range of the force. The advantage of casting the interaction in this form is that the Elliott representation of the shell model wave function can be used to obtain the energies of a system of many particles in a shell without having to diagonalize matrices of enormous size.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] J. P. Elliott, Proc. Roy. Soc. (London) **A245**, 128 and 562 (1958).

**G2. II. Collective Interpretation of Intermediate Shell Model Calculations.*** C. LEVINSON AND M. K. BANERJEE, *Princeton University*.—If the terms in $\Sigma l_i^2$ and $\Sigma l_i\cdot s_i$ can be treated in perturbation theory through 2nd order then the wave functions will be of the type discussed by Redlich[1] and Kurath and Picman.[2] They can be interpreted as representing a system undergoing a collective rotation. The $\Sigma l_i^2$ term gives the same matrix elements that one obtains in the theory of the asymmetric rotator plus effects which can be interpreted as due to a rotation-vibration interaction in a collective model. In addition, the relative magnitude of the $\Sigma l_i^2$ term determines the deformation of the intrinsic rotating system. The $\Sigma l_i\cdot s_i$ term yields, among others, effects interpreted as due to Coriolis forces.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] M. Redlich, Phys. Rev. 110, 468 (1958).
[2] D. Kurath and L. Picman, Nuclear Phys. 10, 313 (1959).

**G3. Pairing Forces in Isotopic Spin Space.*** S. MESHKOV, *University of Pittsburgh*.—One can introduce the idea of a competition between two kinds of pairing effects for two nucleons of angular momentum $j$. In addition to the usual pairing effects in $T=1$ states which lead to a low lying $J=0$ level, there is also a pairing in isotopic spin space which gives low lying $J=1$ and $J=2j$ states. Such a competition between $T=1$ and $T=0$ states manifests itself in the energy level structure of all odd-odd nuclei with $N=Z$. A two-particle calculation using delta function forces in space, and charge spin matrix elements corresponding to usual shell model ones leads to the above competition, with the $J=2j$ state rising as $j$ increases. "Hyper" quasi-spins analogous to the quasi-spins of Kerman,[1] but also containing isotopic spin indices can be introduced into a pairing hamiltonian.

* Supported by the National Science Foundation.
[1] A. Kerman (private communication).

**G4. Lowest Even-parity Odd-spin States in Even-even Nuclei.*** M. K. RAMASWAMY, *The Ohio State University* (induced by P. S. Jastram).—In 1956 Morinaga[1] made a survey of available data concerning the lowest odd-parity states in even-even nuclei. His survey revealed the following features: (1) these states were predominantly $3^-$: there was no case in which even spin was assigned to an odd-parity state, in agreement with the Glaubman-Talmi rule; (2) a plot of the energy of these states vs mass number $A$ could be fitted by $E=67\,A^{-\frac{1}{3}}$ which describes the separation of the two mass parabolas in even-even nuclei; (3) there appeared to be a grouping of these levels at closed shells, the collective $1^-$ states forming a distinct group. A new survey has now been made which indicates a general exception to the Glaubman-Talmi rule: states with spin 3 and even parity have been found throughout the periodic table. A rather remarkable fact emerges, namely, no other odd-spin state with even parity other than $3^+$ has ever been found. The plot of excitation energies of these $3^+$ states as a function of mass number $A$ appears to be fitted by the same relation which applies to the odd-parity odd-spin states.

* Supported by the U. S. Atomic Energy Commission.
[1] H. Morinaga, post-deadline paper at New York Meeting, 1956, and Phys. Rev. 103, 503 (1956).

**G5. Shell Theory of Pb-208.*** W. W. TRUE, *Princeton University*, W. T. PINKSTON, *Vanderbilt University*, AND J. C. CARTER, *Westphalia, Germany*.—A calculation of the lowest odd parity energy levels of $Pb^{208}$ has been made. Shell model states consisting of all states which can arise from promoting $p_{1/2}$ and $f_{5/2}$ neutrons into the $g_{9/2}$ and $i_{11/2}$ shells and $s_{1/2}$ and $d_{3/2}$ protons into the $h_{9/2}$ and $f_{7/2}$ shells were used as basic states in a configuration interaction calculation. The zero order positions of these configurations were determined empirically. A Gauss-shaped two-body potential was used. Two different choices of exchange parameters were considered. Both choices gave a rather good fit to all the observed levels except for the $3^-$ level at 2.615 Mev, the lowest $3^-$ level of the present calculation lying about 1 Mev higher in energy. This supports the assertion of other authors that the 2.615-Mev level arises from a collective octupole oscillation.

* Supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

**G6. A Complex Non-Local Diffuse Boundary Independent Particle Model of Nucleon-Nuclei Scattering and Bound State Phenomena.*** P. J. WYATT, *Aeronutronic*, J. WILLS, *Los Alamos Scientific Laboratory*, AND A. E. S. GREEN, *Convair-San Diego*.—The results of an attempt to unify into a single phenomenological model the positive and negative energy states of nucleons interacting with nuclei are presented. The radii of nuclei are assumed to be connected by a relationship $R=r_0A^{\frac{1}{3}}$ and the well depths by an energy independent relationship $V=V_0\pm(N-Z)/A$. Neutron and proton separation energies are used to adjust five parameters in the real part of the potential. Neutron scattering data is used to adjust two additional absorption parameters appearing in the complex potential. A model is finally obtained which provides a moderately good representation for the gross structure of nucleons interacting with all nuclei and for all energies in the range of interest in classical nuclear physics. A discussion of the limitations of the model is given.

* The investigation was begun at the Los Alamos Scientific Laboratory and continued at the Florida State University with the aid of a grant from the U. S. Atomic Energy Commission and with computational assistance from Eglin Air Force Base arranged by the U. S. Air Force Office of Scientific Research.

**G7. Single Particle States in Deformed Non-Local Diffuse Boundary Potentials.*** R. H. LEMMER, *M.I.T.*, AND A. E. S. GREEN, *Convair-San Diego*.—Using the spherical wave functions generated in a previous investigation by Wyatt, Wills, and Green, the influence of spheroidal deformation is examined with the aid of perturbation theory. The combined calculations yield the energies of single particle states for a diffuse boundary, non-local deformed potential. Specific calculations are performed for light nuclei around $A=25$, and in the rare earth region between $A=150$ and $A=180$. An analysis of nuclear ground state spins and magnetic moments is presented in terms of the computed level schemes and wave functions. The results confirm the general aspects of the Nilsson, Mottelson results as obtained with adjusted harmonic oscillator potentials although some differences arise in detail. The fact that the unperturbed potentials used in this calculation were obtained in the study of Wyatt, Wills, and Green from com-

pletely independent theoretical and experimental considerations is satisfying and further tends to confirm that the phenomenological model has a strong basis in reality. A discussion of the relationship of the phenomenological model to the self consistent nuclear model of Brueckner is given.

* See acknowledgments in previous abstract.

**G8. Effective Charge of Nucleons in Nuclear Matter.*** R. BLIEDEN AND L. WILETS, *University of Washington.*—The proton cloud associated with a given nucleon modifies the effective charge as it enters into shell model calculations of single-particle electric moments. The effective, or renormalized, charge is related in a direct way to the two-body correlation function which can be obtained from various current models of nuclear matter. In particular, we have made calculations employing Puff's[1] correlation function for infinite nuclear matter. In addition to implications for electric multipole transitions, the effective charge is important for the nuclear isomeric shift observed in atomic spectra. For example, in $Hg^{197}$, a difference in the monopole distribution of charge is observed[2] between the ground state and the isomeric state which, on a shell model, differ only in the state of the odd neutron. The neutronic charge is capable of giving an effect the right order of magnitude (as is the effect of nuclear deformation), but uncertainties in the correlation function in the surface region make a close estimate difficult at this time.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. D. Puff, Ph.D. Thesis (Harvard, unpublished).
[2] S. P. Davis and A. Melissinos, Phys. Rev. 115, 130 (1959).

**G9. Approximate Calculation of Nuclear Binding Energies.** V. L. TEPLITZ* AND L. S. RODBERG, *University of Maryland.*—The Brueckner theory of nuclear matter[1] is applied to finite nuclei under the assumption that the range of the two body force is much smaller than the distance over which the nuclear density varies. If this approximation is valid, representation of the single particle wave functions by frequency and amplitude modulated plain waves is reasonable. With these approximations, the binding energy can be obtained in a straightforward manner, as a function of the mass number, size, and shape of the nucleus. The calculation gives too low binding energies. The result may suggest either that the above approximation is not valid or that other effects, such as clustering in the nuclear tail, cannot be omitted from calculations of nuclear binding energies.

* Supported in part by the National Science Foundation.
[1] K. A. Brueckner and J. L. Gammel, Phys. Rev. 109, 1023 (1958).

**G10. Differences in Shape of Real and Imaginary Optical Model Potentials.*** R. F. VERDIER, A. E. EVERETT, AND R. J. GLAUBER, *Harvard University.*—The effect of variation of the potential parameters on the cross section and polarization predicted by the optical model of nucleon-nucleus scattering is being investigated, using a program written for the IBM 704 computer. The program is quite general, in that it allows the strengths, ranges and surface thicknesses of the real and imaginary parts of the central and spin-orbit potentials to be chosen independently. The potentials and charge distribution are taken to have Woods-Saxon shapes, but the program is constructed to accommodate arbitrary shapes. The radial Schroedinger equation for each partial wave is integrated numerically. Differences in the shapes of the real and imaginary potentials have been predicted theoretically.[1] Preliminary calculations carried out for neutrons of 160 mev have shown that even a 10% difference in the surface thicknesses of the real and imaginary central potentials produces a marked filling-in of the diffraction minima of the differential cross section, and hence may result in an improved fit to the experimental data; a difference between the two radii produces an even greater effect. Further results will be discussed.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] R. J. Glauber, Bull. Am. Phys. Soc. Ser. II, 5, 30 (1960).

**G11. Grazing Collisions of Complex Nuclei.*** R. H. DAVIS, *Florida State University.*—By assuming the interaction potential between two complex nuclei to be the sum of the Coulomb, momentum, and optical model potentials, a potential results which possesses a sharp minimum for the high orbital angular momenta characteristic of grazing collisions. The width of the well depends strongly on the orbital angular momentum and the diffuseness parameter. Approximating the well by that of a harmonic oscillator, states are found which corresponds to radial vibrations of the heavy ions about the center of mass of the system. The rotational contributions to the excitation energy of these states was calculated assuming moments of inertia equal to the reduced mass times the square of the separation of the complex nuclei. Using the diffuseness parameter given by Igo,[1] $r_0=1.2f$, and $V=40$ Mev, the vibrational state separation for carbon-carbon and oxygen-oxygen scattering is about 8 and 6 Mev (center of mass), respectively. The computed excitation energies of the states cluster at intervals about equal to those of the vibrational excitations for bombarding energies less than 40 Mev. Because of the sensitivity of the level parameters to the shape of the potential, the observation of such states would provide detailed information about the optical model potential.

* Supported in part by the Air Force Office of Scientific Research.
[1] George Igo, Phys. Rev. Letters 1, 72 (1958).

**G12. Is the Inertia of a Distorted Nucleus Isotropic?** C. W. SHERWIN AND R. D. RAWCLIFFE, *University of Illinois,* AND W. H. JOHNSON, JR., AND R. A. DAMEROW, *University of Minnesota.*—Mass is normally isotropic, although the laws of electricity predict anisotropy in the mass generated by the potential energy of two charges at fixed separation. This anisotropy is cancelled when the charges are restrained by other electrical forces. However it might be observed in asymmetrical nuclei, where the restraining forces are nuclear. In heavy nuclei electrostatic energy generates $\sim 1/300$ of the total mass, $M$. For a rigid prolate spheroid of uniform charge density, electromagnetic mass is larger by $\Delta M$ when the structure is accelerated parallel to the axis of symmetry than when it is accelerated normal to this axis. For $Lu^{175}$, $\Delta M/M$ is calculated to be $14\times10^{-6}$. In the magnetic field of a mass spectrometer, the electromagnetic effect alone should cause the mass line of $Lu^{175}$ (spin $\frac{7}{2}$, atomic state of ion, $^1S_0$) to split into 4 unevenly spaced lines spread over a range of $7 \times 10^{-6}$ M. Examination of this line with a resolution of one part in 50 000 failed to show any structure to 5% of the line width. This gives direct evidence that to this accuracy the asymmetry of inertia of the (negative energy) nuclear field balances that of the electromagnetic field.

## *Invited Paper*

**G13. The Scattering of Photons by Deformed Nuclei.** EVANS HAYWARD, *National Bureau of Standards.* (30 min.)

MONDAY AFTERNOON AT 2:00

Sheraton Hall

(B. J. MOYER presiding)

## *Invited Papers*

**H1. Duration of Nucleosynthesis.** W. A. FOWLER, *California Institute of Technology.* (40 min.)

**H2. Experimental Nuclear Spectroscopy via the Stripping Reaction.** W. C. PARKINSON, *University of Michigan.* (30 min.)

**H3. Recent Experimental Results of Internal Conversion Coefficients.** G. J. NIJGH, *California Institute of Technology.* (30 min.)

**H4. Nuclear Forces and the Angular-Momentum Coupling in Odd-Odd Nuclei.** M. H. BRENNAN, *Princeton University.* (30 min.)

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MONDAY AFTERNOON AT 2:00

Continental Room

(F. AJZENBERG-SELOVE presiding)

## *Nuclear Interactions II*

**HA1. X-Ray Excitation of the 2.13 Mev State of $B^{11}$.†** E. F. KENNEDY* AND W. C. MILLER, *University of Notre Dame.*—The 2.13 Mev state of $B^{11}$ has been excited by a continuous spectrum of x rays produced in a thick gold target by a 2.7 Mev electron beam from our elecrrostatic generator. Nuclear fluorescence was detected at 135° to the x ray beam by a 2 in.×2 in. NaI(Tl) crystal and a 20-channel pulse height analyzer. The yield of 2.13 Mev $\gamma$ rays was measured both with and without a boron absorber in the incident x ray beam. When assuming a spin assignment $J=\frac{1}{2}$ for the 2.13 Mev state[1] and a Debye temperature of 1100°K for (amorphous) boron[2] an analysis of the data yields a value of the mean lifetime of $(4.8\pm0.7)\times10^{-15}$ sec for this state in good agreement with the results of Metzger *et al.*[2]

† Supported in part by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

* Present address: Department of Physics, Holy Cross College, Worchester, Massachusetts.

[1] F. R. Metzger, C. P. Swann, and V. K. Rasmussen, Phys. Rev. 110, 906 (1958).

[2] Johnston, Hersh, and Kerr, J. Am. Chem. Soc. 73, 112 (1951).

**HA2. Level Structure of $B^{12}$ from Resonances in $B^{11}(n,\gamma)B^{12}$.†** W. L. IMHOF, R. G. JOHNSON, F. J. VAUGHN, AND M. WALT, *Lockheed Missiles and Space Research Laboratory.*—Measurements of the cross section for the reaction $B^{11}(n,\gamma)B^{12}$ by an activation technique[1] have indicated resonances at neutron energies of about 430 kev, 1030 kev, 1280 kev, and 1780 kev. Since a level in $B^{12}$ corresponding to the resonance at 1030 kev has not previously been reported, the total cross section of boron in this energy region was measured by a transmission experiment with an over-all energy resolution of about 4 kev. Neutrons were produced by bombarding a thin Li target with protons from a Van de Graaff accelerator; the lower energy group of neutrons which is emitted by the $Li^7(p,n)Be^{7*}$ reaction was excluded by time-of-flight techniques. The total cross sections indicate a resonance at 1027±10 kev. The data were found to be consistent with an *S*-wave resonance of width 10±4 kev and a compound nucleus with $J=1$. From analysis of the capture cross section resonances, preliminary values for the radiation widths of the levels are: 0.3 ev at 430 kev, 0.3 ev at 1027 kev, 0.2 ev at 1280 kev, and 0.9 ev at 1780 kev.

† Supported by the joint program of the United States Atomic Energy Commission and the Lockheed General Research Program.

[1] R. G. Johnson, W. L. Imhof, and F. J. Vaughn, Bull. Am. Phys. Soc. Ser. II, 6, 373 (1959).

**HA3. Elastic and Inelastic Scattering of 14-Mev Neutrons from C and S.** R. L. CLARKE AND W. G. CROSS, *Chalk River Laboratories.*—Energy spectra and angular distributions of 14-Mev neutrons scattered from carbon and sulfur have been measured by a time-of-flight method.[1] Energy resolution at 14 Mev was varied from 5 to 12%. For carbon, the ground and first excited state distributions agree with previous measurements.[2] For a state at 9.7±0.3 Mev $\sigma(\theta)$ is flat from 135° to 70° and at 30° has increased by a factor of three. Neutrons to the 7.6-Mev state are at least three times less numerous. Below 12 Mev excitation no other states were observed. For $S^{32}$, $\sigma_{el}(\theta)$ is in reasonable agreement with calculations of Bjorklund and Fernbach.[3] Between 40° and 110° $\sigma(\theta)$ for the first excited state at 2.24 Mev shows twice the variation predicted by Glendenning,[4] in contrast with the first excited state of $Mc^{24}$ [1] which shows good agreement with theory. A neutron group corresponding to 5.2±0.3 Mev excitation was observed, with a width suggesting that it was due to more than one level.

[1] W. G. Cross and R. L. Clarke, Bull. Am. Phys. Soc. Ser. II, 4, 259 (1959).

[2] For example, J. D. Anderson, C. C. Gardner, J. W. McClure, M. P. Nakada, and C. Wong, Phys. Rev. 111, 572 (1958).

[3] C. St. Pierre, M. K. Machwe, and P. Lorrain, Phys. Rev. 115, 999 (1959).

[4] N. K. Glendenning, Phys. Rev. 114, 1297 (1959).

**HA4. Neutron Yield from the $C^{13}(p,n)N^{13}$ Reaction.*** P. DAGLEY, W. HAEBERLI, J. X. SALADIN, AND R. R. BORCHERS, *University of Wisconsin.*—The neutron yield at 0° from the $C^{13}(p,n)N^{13}$ reaction has been studied for proton energies up to 8.7 Mev using the newly installed tandem accelerator and a "long counter." Measurements were taken at intervals of 10 kev with targets 6–10 kev thick. Between threshold and 5 Mev the relative yield is in good agreement with the work of Bair *et al.*[1] At 5.0 Mev the differential cross section averaged over forward angles (0–15°) is about 8 mb/sterad. There is a sharp drop from 10 to 4 mb/sterad between 5.33 and 5.35 Mev after which the yield increases steadily to 25 mb/sterad at 6.5 Mev. Superimposed on this rise there are peaks at 5.45, 5.54, 5.72, and 6.20 Mev corresponding to energies in $N^{14}$ of 12.60, 12.68, 12.86, and 13.31 Mev, respectively. Between 6.6 and 7.2 Mev there is a broad complex peak with a maximum cross section of about 70

mb/sterad at 6.7 Mev. A similar structure of about 0.3 Mev width was observed near 7.9 Mev.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] J. K. Blair, J. D. Kingston, and H. B. Willard, Phys. Rev. **99**, 575 (1953).

**HA5. $(n,2n)$ Cross Sections of $N^{14}$, $F^{19}$, $Cu^{63}$, $Cu^{65}$, and $Sb^{121}$ in the Energy Region of 13.3 Mev to 15.2 Mev.*** J. H. McCRARY AND I. L. MORGAN, *Texas Nuclear Corporation.*—Excitation functions for the $(n,2n)$ cross sections of the above nuclei have been measured by an activation method. With the use of the $T(d,n)He^4$ reaction, small samples were placed at various angles to the beam to obtain activation by different energy neutrons. The $(n,2n)$ reaction leads to positron emitters for all nuclei reported here. The annihilation radiations were observed with a 2 in.×2 in. NaI(Tl) well counter using the method of Ashe and McCrary[1] for determining the detector efficiency. By using published values of positron decay branching ratios, isotopic abundances, and half-lives, the $(n,2n)$ cross sections were computed for eight values of neutron energy in the aforementioned energy region.

* Supported by the Advanced Research Project Agency of the Department of Defense and monitored by the Research Directorate AFSWC.
[1] J. B. Ashe and J. H. McCrary, Rev. Sci. Instr. (to be published).

**HA6. $N^{14}(p,n)O^{14}$ Differential Cross Section at 14.8 Mev.*** W. W. DAEHNICK, R. SHERR, AND M. K. BANERJEE, *Princeton University.*—In the theory of direct interaction of the $(p,p')$ reaction[1] direct and exchange terms must be considered. For $(p,n)$ reactions only the latter terms occur. With this in mind we are investigating the angular distribution of the $N^{14}(p,n)$ reaction to the ground state of $O^{14}$ (the $T=1$, $O^+$ analog to the 2.31 Mev level in $N^{14}$). Melamine is used as a target and a stilbene crystal as a fast neutron detector. Because of the large negative $Q$ value for the $N^{14}(p,n)O^{14}$ reaction background pulses (mostly $\gamma$ rays) totally cover the neutron spectrum. An efficiency elimination of $\gamma$ ray counts is achieved by a pulse shape discrimination circuit which compares directly the fast component to the *slow* component of the individual pulses. Background neutrons are corrected for by the use of suitable dummy targets, not containing $N^{14}$. Preliminary measurements show a relatively large differential cross section at 40°, a broad minimum around 110°, and a slow rise at backward angles. The data will be compared with theoretical curves obtained by calculating the knockout and stripping exchange terms, and their interference terms in Born approximation.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] C. A. Levinson and M. K. Banerjee, Ann. Phys. (N.Y.) **2**, 471 (1957).

**HA7. Gamma Radiation from $N^{14}(n\gamma)N^{15}$.** R. E. CARTER AND H. T. MOTZ, *Los Alamos Scientific Laboratory.**—Several prominent gamma rays ascribed to nitrogen[1] from a melamine target have been measured with the OWR Compton spectrometer.[2] A line width at half-maximum of 23 kev at 5.3 Mev has allowed the $\gamma$ rays from the first and second excited states[3] of $N^{15}$ to be sufficiently well resolved for analysis. A least-squares fit to this doublet and the corresponding doublet at 5.5 Mev due to transitions from the capturing state at 10.8 Mev yields an energy separation of 29.1±0.8 kev for these two states. Relative intensity measurements for the four $\gamma$ rays between these two excited states, the capturing state ($C$), and the ground state ($O$), are found to be: (1–0)1.00 ±0.06, (2–0)0.59±0.04, (C-2)0.40±0.02, (C-1)0.18±0.01. These intensities indicate that only 18±2% of the population of the first excited state is accounted for by direct transitions from the capturing state. A search is being made for the missing transitions to the first excited state. The Compton spectrometer energy scale is based on the 2753.3 kev line of $Mg^{24}$, and gives $N^{15}$ levels that are lower by 1.9 parts in $10^3$ from the accepted values.[3]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. A. Bartholomew and P. J. Campion, Can. J. Phys. **35**, 1347 (1957).
[2] W. D. Barfield, H. T. Motz, and R. E. Carter, Bull. Am. Phys. Soc. Ser. II, **5**, 44 (1959).
[3] F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. **11**, 1 (1959).

**HA8. Energy Dependence of the $O^{16}(p,\alpha)N^{13}$ Reaction.*** D. R. MAXSON,† *Princeton University.*—The $O^{16}(p,\alpha)N^{13}$ activation cross section was measured by Whitehead and Foster,[1] who found that the excitation curve has three prominent maxima below 16 Mev. Their results were confirmed and extended to 19 Mev by Rouse.[2] In the experiment reported here, angular distributions of alpha particles from the $O^{16}(p,\alpha)N^{13}$ ground state reaction were measured at 9 bombarding energies from 13.5 to 18.1 Mev. In addition, the variation of the cross section at 70 deg was observed as the proton energy was changed in 200 kev steps from 10.5 to 19 Mev. A thin Mylar target was used and the alphas were detected with an ionization chamber. The angular distributions are oscillatory but not of the form predicted by the plane wave pickup or knockon theories, and the variation with energy is much more pronounced than would be expected for a simple idirect reaction. The excitation curve has a minimum at $E_p \cong 16.5$ Mev, and the angular distributions are markedly different above and below this energy.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Now at Brown University.
[1] A. B. Whitehead and J. S. Foster, Can. J. Phys. **36**, 1276 (1958).
[2] G. R. Rouse, B.S. thesis, Princeton University, May, 1958 (unpublished).

**HA9. High-Resolution Measurements of the $O^{16}(p,\alpha)N^{13}$ Excitation Function.*** E. L. HAASE AND H. A. HILL, *Princeton University.*—The $O^{16}(p,\alpha)N^{13}$ activation cross section was measured from 12 to 18 Mev with an energy resolution of 30 kev. The results were essentially the same as obtained by Whitehead and Foster[1] and Rouse[2] using poorer resolution except for one very narrow resonance. As the proton energy increases through this resonance, the cross section first rises 7% to a maximum, then drops 33% to a minimum, and finally rises 6%. The peak and valley have a width at half-maximum of 30 kev and peak and valley are separated by 60 kev. The proton energy at halfway down the drop was determined, using the limp wire technique, to be 14.600±0.020 Mev. This resonance is well suited for calibration purposes. The absence of any other fine structure in the 12- to 18-Mev region strongly suggests that the broad peaks represent "giant" resonances of some sort.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] A. B. Whitehead and J. S. Foster, Can. J. Phys. **36**, 1276 (1958).
[2] G. R. Rouse, B.S. thesis, Princeton University, May, 1958 (unpublished).

**HA10. Angular Distribution of the $O^{16}(d,t)O^{15}$ Ground State Reaction.*** E. L. KELLER, *University of Pittsburgh.*—Fifteen-Mev deuterons from the University of Pittsburgh cyclotron have been used to study the $O^{16}(d,t)O^{15}$ ground state reaction. The angular distribution of this triton group has been fitted with an $l_n=1$, $r_0=4.75f$ Butler stripping curve and the reduced width has been extracted. The measured peak cross section, 0.842±0.219 mb/sr at $\theta_{cm}=17.9°$, yields $A\Theta^2=2.38$ where $A$ is the normalization factor for the triton wave function. Using the reasonable value of $A=195$,[1] a single particle reduced width of $\Theta_s^2=0.0031$ is obtained. This uncommonly low value for a $1p$ single particle reduced width possibly can be explained by an unusually strong dependence

of $\Theta_0^2$ on $Q$ value ($Q=-9.395$ Mev in the present case) and/or an abnormally high value for A.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] M. H. Macfarlane and J. B. French, "Stripping reactions and the structure of light and intermediate nuclei" (University of Rochester Rept. NYO 2846, 1959).

**HA11. $O^{18}$ Ground State Wave Function as Determined by Analysis of the Reaction $O^{18}(d,t)O^{17}$.*** J. C. ARMSTRONG, K. S. QUISENBERRY, AND S. MESHKOV, *University of Pittsburgh.*—Nickel oxide foils, prepared from $O^{18}$ enriched gas, have been used to study the reaction $O^{18}(d,t)O^{17}$ at a deuteron bombarding energy of 15 Mev. Angular distributions of triton groups corresponding to the $O^{17}$ ground state, 0.87-, 3.85-, 4.55-, 5.08-, and 5.38-Mev levels have been obtained. Relative reduced widths were extracted using Butler stripping curves having $l_n$ values of 2, 0, 3, 1, 2, and 1, respectively. Assuming reasonable values for the single particle reduced widths, the $O^{18}$ ground state wave function has been written as a sum of $O^{16}+(nlj)^2$ terms. Comparisons will be made with various calculations. Though both the 3.06- and 5.22-Mev levels in $O^{17}$ were observed, their angular distributions have not been obtained.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**HA12. Elastic Scattering and Reactions of Protons on $O^{18}$.*** A. C. L. BARNARD, J. A. JACOBS, R. R. CARLSON, AND C. C. KIM, *State University of Iowa.*—$O^{18}(p,p)O^{18}$ and the reactions $O^{18}(p,p'\gamma)O^{18}$, $O^{18}(p,\alpha_0)N^{15}$ and $O^{18}(p,\alpha_{1,2}\gamma_{1,2})N^{15}$ were studied using a thin gas target, CsI (Tl) detectors and a Van de Graaff accelerator. Absolute differential cross sections were measured at the two laboratory angles 86.8° and 159.5° over the range of incident proton energies between 790 and 3550 kev and angular distributions for $p$ and $\alpha_0$ were measured at several energies. Relative yield curves were obtained for $O^{18}(p,\gamma)F^{19}$ in the same energy range as above. Five $F^{19}$ levels were observed which have not previously been reported and some new decay modes for previously known levels were observed.

* Supported in part by the U. S. Atomic Energy Commission.

**HA13. Analysis of Experimental Results on $O^{18}+p$.*** J. A. JACOBS, A. C. L. BARNARD, R. R. CARLSON, AND C. C. KIM, *State University of Iowa.*—Some of the anomalies in the differential cross section for elastic scattering were fitted using a one-level approximation of the dispersion theory, which was also used to fit the elastic-scattering angular distributions at the resonance energies. The angular distributions of $\alpha_0$-particles were fitted by reaction-theory calculations, including where necessary the effect of interference from overlapping levels. Spin and parity assignments were then made to some $F^{19}$ levels as follows: $E_x=8.763$ Mev $j\pi=\frac{1}{2}^+$, $E_x=9.609$ Mev $j\pi=\frac{3}{2}^-$, $E_x=9.636$ Mev $j\pi=\frac{3}{2}^-$, $E_x$9.636 Mev $j\pi=\frac{5}{2}^+$ and $E_x=9.865$ Mev $j\pi=\frac{1}{2}^+$.

* Supported in part by the U. S. Atomic Energy Commission.

**HA14. Lifetimes of Excited States in Al and Mg.*** F. R. METZGER, C. P. SWANN, AND V. K. RASMUSSEN, *Bartol Research Foundation.*—The gamma rays resulting from the bombardment of Al and Mg with protons of 3.3 to 4.2 Mev energy were used to excite low lying levels in $Al^{27}$, $Mg^{24}$, and $Mg^{25}$. By combining the results of self-absorption and resonance scattering studies with measured branching ratios, the following mean lives were obtained: $\tau=1.7\times10^{-12}$ sec for the 1.01 Mev $\frac{3}{2}$+level in $Al^{27}$; $\tau=(g_2/g_1)2.7\times10^{-14}$ sec for the 2.21 Mev level in $Al^{27}$; $\tau=1.6\times10^{-13}$ sec for the 1.37 Mev 2+ level in $Mg^{24}$, and $\tau=2.2\times10^{-14}$ sec for the 1.61 Mev $\frac{5}{2}$+ level in $Mg^{25}$. The angular distribution of the 1.01 Mev resonance radiation was found to be of the form $W(\theta)=1+(0.02\pm0.13)$ $P_2(\cos\theta)$, that of the 2.21 Mev radiation was measured as $W(\theta)=1+(0.23\pm0.03)$ $P_2(\cos\theta)$.

* Assisted by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**HA15. $Na^{23}(\alpha,p)Mg^{26}$ and $Si^{28}(\alpha,p)P^{31}$ Angular Distributions at ~19 Mev.*** W. D. PLOUGHE, E. BLEULER, AND D. J. TENDAM, *Purdue University.*—The angular distributions of protons from the $Na^{23}(\alpha,p)Mg^{26}$ and $Si^{28}(\alpha,p)P^{31}$ reactions which leave the residual nucleus in its ground, first excited, and second excited states have been measured at approximately 19 Mev over the angular range of 12° to 170° in 5° intervals. The sodium target was in the form of NaOH which was vacuum evaporated on a Mylar film. A thin quartz foil was used as the silicon target. All the angular distributions show the characteristic forward peaking of direct interactions. In the $Na^{23}(\alpha,p)Mg^{26}$ reaction the intensity of the protons which leave the $Mg^{26}$ nucleus in its first excited state is greater by a factor of about five than that of the ground state group while in the $Si^{28}(\alpha,p)P^{31}$ reaction the intensities of the two groups are comparable. In the $Na^{23}(\alpha,p)Mg^{26}$ reaction and the angular distribution of the ground state protons has been fitted with the square of the spherical Bessel function with $l=2$ and $R=7.4f$. Unique $l$ values are not predicted for the first and second excited states. For the $Si^{28}(\alpha,p)P^{31}$ reaction unique $l$ values of 0, 2, and 2 are allowed for the ground, first excited, and second excited state proton groups, respectively. A comparison of the theoretical and experimental angular distributions will be presented.

* Supported in part by the U. S. Atomic Energy Commission.

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## TUESDAY MORNING AT 9:30

## Continental Room

## (P. T. DEMOS presiding)

## *Nuclear Interactions III*

**I1. Inelastic Scattering of Deuterons from $Mg^{25}$ and $Mg^{26}$.*** A. G. BLAIR AND E. W. HAMBURGER, *University of Pittsburgh.*—Thin metallic targets enriched in $Mg^{25}$ and $Mg^{26}$ were bombarded with 15-Mev deuterons from the University of Pittsburgh cyclotron. Inelastically scattered deuterons from target nuclei states up to about 5-Mev excitation were magnetically analyzed and detected with the aid of nuclear emulsion plates at laboratory scattering angles ≈12°, 30°, and 60°. The only large deuteron groups scattered by the $Mg^{25}$ nuclei came from the 1.61-Mev (7/2+) level and from a level corresponding in energy to the 3.40-Mev (3/2−) state. At $\theta_{lab}\approx30°$, these cross sections are 3.74 mb/sr and 1.52 mb/sr, respectively,

while the cross sections for the 0.58- and 0.98-Mev levels, for example, are $\approx$0.13 mb/sr. It is suggested that the strong deuteron group at 3.4 Mev may come largely from a 9/2+ ground state rotational band level which, in analogy with the $Al^{25}$ nucleus, should appear at approximately this excitation energy. In the $Mg^{26}(d,d')Mg^{26}$ reaction, the cross sections at $\theta_{lab} \approx 30°$ are found to be 8.38 mb/sr for the 1.83-Mev (2+) level, 1.72 mb/sr for the 2.97-Mev (2+) level, 0.65 mb/sr for the 4.35-Mev (2+) level, and $\leq$0.60 mb/sr for the other levels seen. A previously unreported $Mg^{26}$ level also was found from this reaction, and by means of a $Mg^{25}(d,p)Mg^{26}$ reaction was determined to lie at 3.614$\pm$0.020 Mev.

* Work done in the Sarah Mellon Scaife Radiation Laboratory and assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**I2. The 3.51- and 3.79-Mev Levels in $Si^{30}$.** C. BROUDE AND H. E. GOVE, *Chalk River Laboratories.*—Cascade gamma rays from the decay of the second and third excited states of $Si^{30}$ have been observed following the inelastic scattering of protons from a thin separated $Si^{30}$ target in the range from 5.0- to 5.5-Mev bombarding energy. Gamma rays of 1.27 and 1.55 Mev have been observed in coincidence with the 2.24-Mev radiation from the first excited state and a cross over radiation from the 3.51-Mev level has been observed in the direct gamma-ray spectrum. No ground state decay of the 3.79-Mev level has been detected. The coincidence correlations between the cascading gamma rays from each of these levels have been measured in six geometries. In these geometries either the first or second gamma ray is detected in the horizontal plane at 90° to the beam and the other is measured both in and out of this plane. The direct correlation of the 3.51-Mev radiation has also been measured. These observations suggest spins of 1 or 2 for the 3.51-Mev level and 0 for the 3.74-Mev level. The method of theoretical interpretation of these correlations has previously been described,[1] and a full analysis of the results will be presented.

[1] R. Batchelor, A. J. Ferguson, H. E. Gove, and A. E. Litherland, Bull. Am. Phys. Soc. Ser. II, 4, 445 (1959).

**I3. Disintegration of $K^{39}$ by Fast Neutrons.*** H. P. HAENNI, R. BASS, AND T. W. BONNER, *The Rice Institute.*—A KJ(Tl) crystal, 6 mm in diameter and 6 mm thick, was bombarded with fast neutrons of energies from 2.4 to 8.7 Mev. Tritium and deuterium gas targets were used in connection with the Rice Institute Van de Graaff accelerator to obtain monoenergetic neutrons with an energy spread of approximately 100 kev from the reactions $T(p,n)He^3$ and $D(d,n)He^3$. Scintillations due to protons and $\alpha$ particles from the reactions $K^{39}(n,p)A^{39}$ and $K^{39}(n,\alpha)C^{36}$ produced in the crystal were recorded with a 256-channel pulse-height analyzer. Preliminary estimates indicate the following cross sections for the ground state groups: $K^{39}(n,p)A^{39}$ ($Q$=0.22 Mev): 83 mb at $E_n$=2.4 Mev, 97 mb at $E_n$=3.2 Mev, and 11 mb at $E_n$=8.7 Mev; $K^{39}(n,\alpha)Cl^{36}$ ($Q$=+1.35 Mev): 3 mb at $E_n$=2.4 Mev and 20 mb at $E_n$=3.2 Mev. At neutron energies above 3.5 Mev the analysis of the pulse-height spectra is complicated by the appearance of additional groups of protons and $\alpha$ particles going to excited states of the final nuclei of the above reactions. A total of at least 8 proton groups and 4 $\alpha$ particle groups is observed. Work on the identification of these groups is in progress.

* Supported by the U. S. Atomic Energy Commission.

**I4. Disintegration of $Ca^{40}$ by Fast Neutrons.*** R. BASS, T. W. BONNER, AND H. P. HAENNI, *The Rice Institute.*—The reactions $Ca^{40}(n,p)K^{40}$ and $Ca^{40}(n,\alpha)A^{37}$ were studied by bombarding small crystals of $CaF_2$ and $CaWO_4$ with monoenergetic neutrons ranging in energy from 2 to 8 Mev and observing the scintillations produced by protons and $\alpha$ particles in the crystals. A solid Zr-T target and a $D_2$ gas target were used in connection with the Rice Institute Van de Graaff accelerator to obtain neutrons with an energy spread of approximately 100 kev from the reactions $T(p,n)He^3$ and $D(d,n)He^3$. Pulse-height spectra were recorded with a 256-channel pulse-height analyzer. For protons of energy above 3 Mev the pulse-height resolution was 12–15% with $CaF_2$ crystals and 10–12% with $CaWO_4$ crystals; the light output from both crystals was found to be 3 to 5 times smaller for $\alpha$ particles than for protons of equal energy. Two peaks due to protons going to the ground and first three excited states of $K^{40}$, and one peak due to $\alpha$ particles going to the ground state of $A^{37}$ are predominant in the pulse-height spectra; further groups of protons and $\alpha$ particles can be distinguished at neutron energies above 4 Mev. A crude preliminary analysis of the results yields cross-section values for the highest energy proton peak rising from 10 mb at $E_n$=2 Mev to 200 mb at $E_n$=3–4 Mev and dropping to 50 mb near $E_n$=8 Mev. Further work with improved energy resolution is in progress.

* Supported by the U. S. Atomic Energy Commission.

**I5. Mass and Energy Levels of $Sc^{41}$ by $Ca^{40}(He^3,d)Sc^{41}$ and $Ca^{40}(d,n)Sc^{41}$ Reaction Scattering.*** H. E. WEGENER AND W. S. HALL, *Los Alamos Scientific Laboratory.*—The $Q$ values for the $Ca^{40}(He^3,d)Sc^{41}$ reaction and excited states are found to be in disagreement with published values.[1,2] The $Q$ values for the calcium reaction are measured with an energy scale established by the $C^{12}(He^3,d)N^{13}$ and $Be^9(He^3,d)B^{10}$ reactions. The $Ca^{40}(He^3,d)Sc^{41}$ $Q$ values for the ground to fourth excited states are as follows: $-4.47\pm0.10$, $-6.16\pm0.15$, $-7.82\pm0.15$, $-9.57\pm0.20$, $-10.48\pm0.20$ Mev. Angular distributions of the deuterons for the $Ca^{40}(He^3,d)Sc^{41}$ reaction at 25 Mev will be shown. An assignment of $l_p$=3 fits the ground state; however, the higher levels cannot be fitted uniquely. Predicted single particle energy levels[3] are in agreement with those observed. Preliminary $Q$ values for the $Ca^{40}(d,n)Sc^{41}$ reaction measured with time-of-flight equipment are $-1.32\pm0.07$ and $-2.85\pm0.03$ Mev. Each of the ground and first excited state measurements on the $Ca^{40}(He^3,d)Sc^{41}$ and $Ca^{40}(d,n)Sc^{41}$ reactions differ by $0.67\pm0.10$ Mev from their respective currently accepted values, resulting in a revised mass of $Sc^{41}$ of 40.982355 $\pm$0.0001 amu.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] D. R. Elliot and L. D. P. King, Phys. Rev. 60, 489 (1941).
[2] H. S. Plendl and F. E. Steigert, Bull. Am. Phys. Soc. Ser. II, 4, 18 (1959).
[3] C. M. Class, R. H. Davis, and J. H. Johnson, Phys. Rev. Letters 3, 41 (1959).

**I6. Nuclear Electric Monopole Transition in $Ca^{42}$.*** N. BENCZER-KOLLER, M. NESSIN, AND T. H. KRUSE, *Columbia University.*—An enriched target of $Ca^{42}CO_3$ (82.5% $Ca^{42}$) on a 0.000125-in. iron foil backing was bombarded with protons from the Van de Graaff generator from 3.6 to 6.3 Mev. A 1.84-Mev conversion electron line was observed with the Columbia, Alburger-type intermediate image spectrometer[1] from the 1.84-Mev second excited state of $Ca^{42}$. A continuous positron spectrum was also detected having an end point of $0.83\pm0.02$ Mev. The preliminary ratio of positron to 1.84-Mev electron yield is consistent with theoretical prediction for an EO transition, as is the positron spectra shape. 0.305-Mev internal conversion electrons were observed corresponding to the transition between the 1.84 and the $2^+$ 1.53-Mev states. The ratio of 1.84- to 0.305-Mev electron yields is $1.0\pm0.1$. The iron foil gave a flat background in energy regions of interest. These results are consistent with recent assignments of spin zero to this state.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] M. Nessin, K. E. Eklund, and T. H. Kruse, Bull. Am. Phys. Soc. Ser. II, 4, 278 (1959).

**I7. $(p,n)$ Cross Sections from 4 to 6.5 Mev.*** H. TAKETANI AND W. PARKER ALFORD, *University of Rochester.*—Absolute $(p,n)$ cross sections have been measured for $Ti^{47}$, $V^{51}$, $Cr^{53}$, $Co^{59}$, and $Cu^{63}$ at energies between 4 and 6.5 Mev. Cross sections for Ti, Cr, and Cu were determined from measurements of the annihilation radiation from the irradiated foils; those for V and Co were measured with a long counter which had been calibrated using the measured $Cu^{63}$ cross section. These data plus earlier measurements[1] of inelastic proton cross sections have been used to estimate total proton absorption cross sections. A comparison of the measurements with cross sections calculated using an optical model will be presented.

* Work supported by the U. S. Atomic Energy Commission.
[1] F. D. Seward, thesis, University of Rochester (unpublished).

**I8. Capture-Gamma Determination of $V^{51}$ Levels.*** JOSEPH E. SCHWAGER,† *Lawrence Radiation Laboratory, Livermore* (introduced by Burton J. Moyer).—A fast-coincidence scintillation spectrometer has been developed for thermal neutron capture-gamma studies at the Livermore one-megawatt pool-type reactor. Cascade radiations for $V^{51}$ have been observed and a decay scheme established. Spin assignments are proposed and the level order for the $(1f_{7/2})^3$ proton configuration has been established as $7/2^-$ (ground state), $5/2^-$, $3/2^-$, $11/2^-$, $9/2^-$, and $15/2^-$ with excitation energies of 0.32, 0.93, 1.61, 1.81, and 2.70 Mev, respectively. Calculations by other authors for the short-range force approximation and weak surface-coupling effects appear to give the best match between theory and experiment. A previously published calculation using experimentally measured splittings of the $j^3$ configuration together with tabulated coefficients of fractional parentage give excellent agreement with experiment. Evidence was found for $(1f_{7/2})^3\,2p_{3/2}$ and $(1f_{7/2})^2\,1f_{5/2}$ single-particle excitations at 2.41 and 2.55 Mev, respectively, as well as for additional low-spin states between 2.70 and 3.38 Mev which possibly represent even states resulting from excitation of a lower-shell proton to give a $(1f_{7/2})^4$ configuration plus a proton hole in the vacated shell.

* Performed under the auspices of the U. S. Atomic Energy Commission.
† Commander, U. S. Navy on special assignment at Lawrence Radiation Laboratory.

**I9. Stripping Analysis of the $V^{51}(d,p)V^{52}$ Reaction.*** H. A. ENGE, W. W. BUECHNER, AND J. H. WOJTASZEK, JR.† *Massachusetts Institute of Technology.*—The MIT-ONR Van de Graaff accelerator and broad-range spectrograph were used to study angular distributions of protons emitted from a $V^{51}$ target bombarded with 7.5-Mev deuterons. Some preliminary results of the stripping analysis are given in Table I. Levels at

TABLE I

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ex (Mev) | 0 | 0.020 | 0.136 | 0.431 | 0.690 | 0.787 | 0.841 | 1.406 | 1.550 | 1.733 |
| $l_n$ = | 1 | 1 | 1 | 1 | (0) | 1 | 1 | 1 | 1 | 0 |
| Ex (Mev) | 1.752 | 1.786 | 2.084 | 2.125 | 2.152 | 2.292 | 2.522 | 2.728 | 2.757 | 2.843 |
| $l_n$ = | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 |

0.530, 0.625, 0.723, 1.280, 1.484, 1.653, 1.827, 2.347, 2.412, 2.455, 2.563, 2.610, 2.630, and 2.823 Mev do not show typical stripping distributions or are so weak that an $l_n$ value could not be assigned. Seventeen additional levels up to 3.624-Mev excitation will be reported.

* This work has been supported in part with funds provided by the U. S. Atomic Energy Commission, by the Office of Naval Research, and by the U. S. Air Force Office of Scientific Research.
† Now at the University of Rochester.

**I10. Level Densities in Medium Heavy Nuclei from $(p,\alpha)$ Reactions.*** F. PAUL BRADY AND R. SHERR, *Princeton University.*—Protons of about 17.5 Mev were used to produce $(p,\alpha)$ rections in V, Fe, Co, Ni, and Rh. The entire energy spectra of the $\alpha$ particles were measured at various angles. For angles $\geq 90°$ these spectra are Maxwellian in shape and essentially isotropic, and have been analyzed in terms of the statistical theory for compound-nucleus reactions. With the reaction cross sections of Shapiro[1] and an interaction radius[2] $R=1.4A^{\frac{1}{3}}+2.2$, the level density has the form $\exp(E_x/T)$ for $E_x=3-12$ Mev with $T=1.42$, 1.21, 1.46, 1.20, and 1.17 (all $\pm 5\%$) for the residual nuclei $Ti^{48}$, $Mn^{53}$, $Fe^{56}$, $Co^{55,57}$, and $Ru^{100}$, respectively. Igo's reaction cross section[3] lead to the same result with slightly higher temperatures. The Fermi level density $\exp(aE_x)^{\frac{1}{2}}$ can be obtained if a 10% increase in $R$ is assumed. This larger radius leads to total cross sections more than three times as great as the experimental values, while the smaller radius gives reasonable agreement.

* This was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
[1] M. M. Shapiro, Phys. Rev. **90**, 171 (1953).
[2] D. D. Kerlee, J. S. Blair, and F. W. Farwell, Phys Rev. **107**, 1343 (1957).
[3] G. Igo, Phys. Rev. **115**, 1665 (1959).

**I11. $Ni(p,\alpha)$ and $Ni(p,p')$ Reactions at Small Angles with 17.6-Mev Protons.*** H. HILL AND R. SHERR, *Princeton University.*—At small angles the large preponderance of elastically scattered protons in medium-heavy nuclei make observation of other reactions with scintillation spectrometers difficult. By using a double-focusing magnetic spectrometer, successful measurements have been made down to 10°. The focused reaction products are observed with a CsI crystal, in which $p$, $d$, and $\alpha$'s are clearly separated because the $\alpha$ response is about 0.75 that of protons of the same energy in the 7- to 17-Mev region. The continuum of the $\alpha$ spectrum for $Ni(p,\alpha)Co$ at 28° with 17.6-Mev protons was measured. It was found to be in excellent agreement both in absolute cross section and shape with the observations reported by Brady and Sherr.[1] Only two narrow $\alpha$ groups were seen, with $Q$'s of $-1.40\pm0.15$ and $-0.15\pm0.15$, in good agreement with the $Q$ values for the ground states of $Co^{55}$ and $Co^{57}$ ($-1.34\pm0.01$ and $-0.03\pm0.03$ Mev). The yield of inelastic protons, corresponding to the first excited levels at about 1.4 Mev of $Ni^{58}$ and $Ni^{60}$ were measured from 30° to 10°. The cross section decreases appreciably as the angle decreases, in qualitative agreement with direct interaction theory.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
[1] F. P. Brady and R. Sherr, Bull. Am. Phys. Soc. Ser. II, **5**, 249 (1960), this issue.

**I12. $(p,t)$ Differential Cross Sections at 22 Mev.** J. B. BALL, *Oak Ridge National Laboratory.**—The energy spectra of tritons from the bombardment of V, Co, Nb, Rh, and Au with 22-Mev protons were measured. The tritons were detected with a proportional counter-NaI scintillation counter telescope in a system which allowed simultaneous recording of proton, deuteron, and triton spectra. The triton spectra show marked structure consistent with a strong single-particle direct-interaction mechanism. The cross section for the ground state transition at 30° exhibits a monatomic increase with target mass from a value of 30 $\mu$b/sr for V to 560 $\mu$b/sr for Au. The angular distribution for the ground state transition in Co indicates an $l=0$ transition consistent with the double-pickup mechanism. The integrated cross section is of the order of 1 mb.

* Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

TUESDAY MORNING AT 9:30

National Bureau of Standards, East Building

(F. N. FRENKIEL presiding)

## *Fluid Dynamics*

**IA1. Spectral Transfer in Isotropic Turbulent Mixing.*** E. E. O'BRIEN, *The Johns Hopkins University* (introduced by S. Corrsin).—The mixing of a dynamically passive, chemical contaminant in isotropic turbulence[1] has been studied with the simplifying assumption that quadruple correlations are related to double correlations as for Gaussian variables.[2,3] The small time behavior of the concentration spectral transfer functions has been calculated for simple initial velocity and concentration spectra. It differs qualitatively from the turbulent energy transfer[1] only at small wave numbers.

* Supported by Mechanics Branch, Office of Naval Research.
[1] S. Corrsin, J. Appl. Phys. **22**, 469 (1951).
[2] I. Proudman and W. H. Reid, Phil. Trans. Roy. Soc. (London) **247**, 163 (1954).
[3] T. Tatsumi, Proc. Roy. Soc. (London) **A239**, 16 (1957).

**IA2. On the Generation of Sound by Supersonic Turbulent Shear Layers.** O. M. PHILLIPS,* *The Johns Hopkins University* (introduced by S. Corrsin).—The general problem of sound generation of high Mach number is formulated in terms of a convected wave equation, which includes such physical effects as sound generation, refraction, convection, and scattering. The supersonic turbulent shear layer is examined in detail. When the Mach number $M \gg 1$, the dominant contribution comes from eddy Mach waves, and an asymptotic solution is found for large $M$ by a Green's function technique. It is found that radiation with a given frequency $n$ and wave number $\mathbf{k}$ can be associated with a corresponding critical layer in the shear zone. The mean square pressure fluctuations $\bar{p}^2 \propto M^5$ for $M \gg 1$, and the acoustic efficiency $\eta \propto M^{-5}$ for $M \gg 1$, indicating the existence of a maximum acoustic efficiency near $M = 1$. The directional distribution also is discussed. The predictions of the theory are supported qualitatively by the few available experimental observations.

* Supported by the Office of Naval Research.

**IA3. On Cylindrical Hydromagnetic Resonators.*** R. GAJEWSKI† AND O. K. MAWARDI, *Massachusetts Institute of Technology*.—The behavior of hydromagnetic waves in a cylindrical resonator of arbitrary cross section is examined. The conducting fluid inside the resonator is permeated with a steady uniform magnetic field parallel to the generators of the cylinder. The eigenfrequency spectrum is derived for all possible modes and types of waves. It is shown that a TLA (Transverse Longitudinal Acoustic) type wave when reflected from a rigid conducting termination generates an accompanying TLM (Transverse Longitudinal Magnetohydrodynamic) type wave and vice versa. Energy losses due to the finite viscosity and electrical conductivity of the fluid as well as to the finite conductivity of the walls are then estimated for the case of T (purely Transverse) type waves. A $Q$ factor for T type waves is subsequently calculated.

* Supported in part by the Cambridge Air Force Research Center.
† Sloan Foreign Postdoctoral Fellow, on leave from the Institute for Nuclear Research, Warsaw, Poland.

**IA4. Fluid Flow through a Porous Channel.*** W. E. WAGEMAN AND F. A. GUEVARA, *Los Alamos Scientific Laboratory*.—Approximate solutions of the equations of motion governing laminar incompressible fluid flow through a cylindrical channel with a porous wall are derived. The invalidity of an approximation in the solution of these equations under certain circumstances is pointed out, and the results of a numerical integration in the region where the approximation is invalid are indicated. A brief description is given of an experiment to verify the calculations, and some interesting results are noted.

* Work done under the auspices of the U. S. Atomic Energy Commission.

**IA5. Continuum Infrared Spectrum of Shock Heated Air.*** RAYMOND L. TAYLOR, *Avco-Everett Research Laboratory* (introduced by Bennett Kivel).—The continuum infrared radiation from a sample of air heated to an equilibrium temperature of 8000°K behind a reflected shock wave has been observed over the wavelength range of 2–7 $\mu$. The radiation, which was monitored axially down the center of the shock tube to minimize the effects of impurities in the boundary layer, was dispersed in a Perkin Elmer M83 monochromator using a $CaF_2$ prism and detected with a Westinghouse type 812 Au-doped Ge photoconductor. By calibrating the optics and detector against a standard source, the absolute intensity of the radiation was determined and compared with a previous study[1] in the wavelength range of 1–4.8 $\mu$. The radiation is expected to be primarily associated with free-free scattering of electrons by atoms and molecules. The intensity of the radiation was found to decrease with increasing wavelength. However, a slight "bump" in the general level of intensity was observed in the region of 3.5–4.0 $\mu$. Some results on the temperature dependence of the radiation from shock-heated air are also presented.

* This work was supported by the Advanced Research Projects Agency and the Army Rocket and Guided Missile Agency.
[1] T. Wentink, Jr., W. Planet, P. Hammerling, and B. Kivel, J. Appl. Phys. **29**, 724 (1958).

**IA6. Shock Tube Measurement of the Decomposition of Nitric Oxide.** JOHN J. ALLPORT, *Lockheed Missiles and Space Division*.—The dissociation of pure nitric oxide has been studied using a shock tube for the temperature range 3000°K to 4500°K. The decomposition was observed by measuring the decrease in infrared radiation from both the fundamental and first overtone bands of nitric oxide. At 3400°K decomposition proceeds as an isothermal process.[1] The observed time dependence of the reaction agrees with the mechanism described by Kaufman and Kelso,[2] wherein the concentration of atomic oxygen becomes rate controlling above about 1800°K.

[1] S. T. Demetriades and H. Arocste, Jet Propulsion Lab. Rept. No. 3.
[2] F. Kaufman and J. R. Kelso, J. Chem. Phys. **23**, 9, 1702 (1955).

**IA7. Vibrational Relaxation of Carbon Monoxide in the Shock Tube.*** D. L. MATTHEWS, *Carleton University, Canada*.—An interferometer and shock tube have been used to observe the rate of vibrational equilibration of pure CO in the temperature range 2000°–5000°K. Experiments were also done with CO containing controlled amounts of the following impurities, one at a time: $H_2$, $N_2$, $O_2$, $CO_2$, $H_2O$. Only $H_2O$ and to a lesser extent $CO_2$ were found to produce a significant reduction in the relaxation time. The pure gas was considered sufficiently free of $H_2O$ and $CO_2$ (well under one part in $10^4$) for the relaxation time to be unaffected. Relaxation times at atmospheric

pressure in the pure gas ranged from about 50 μsec at 2000° to 2.2 μsec at 5000°. Nitrogen, by comparison, relaxes about twice as slowly at these temperatures. The low-temperature end of these observations overlaps the high-temperature end of those of a previous study,[1] in which infrared emission was used to follow the relaxation; the times observed by these workers in the region of overlap were about 2.5 times longer than those reported here. In the opinion of the author, this discrepancy cannot be ascribed to impurities.

* Experiments performed at Princeton University and supported by the Office of Naval Research.
[1] Windsor, Davidson, and Taylor, Seventh Symposium (International) on Combustion (preprint).

**IA8. Nitrogen Opacity Measurements.*** D. E. BUTTREY, *Lockheed Missiles and Space Division* (introduced by S. W. Kash).—Absolute intensity measurements of radiation from shock-heated nitrogen have been made for temperatures up to 1.5 ev and densities of one to three-tenths normal. Absorption coefficients have been inferred for the $N_2^+$ first negative system and a continuum attributed mainly to photoelectric recombination in atomic nitrogen. Trace quantities of hydrogen were introduced into the nitrogen and the Balmer line profiles observed were compared with the Kolb-Griem-Shen theory[1] to obtain ion densities behind the reflected shock. Temperatures were determined from relative intensities of the Balmer lines, from the intensity distribution in the rotational-vibrational systems of $N_2^+$, and from comparison of the measured incident and reflected shock velocities with the solutions to the Rankine-Hugoniot equations.

* This work was partially sponsored by Air Force Special Weapons Center.
[1] Phys. Rev. (to be published).

**IA9. Impulse Tube: An Experimental Separation of Ohmic Heating and Magnetic Driving.** JOHN R. BANISTER, *Sandia Laboratory.*—The performance of an electrical shock tube which passes a brief unidirectional capacitor discharge through a plasma in the presence of a transverse applied magnetic field has been examined. The tube behavior was found to be predicted by the usual hydrodynamic shock tube theory modified to allow for the directed motion imparted by the ponderomotive force ($J \times B$) provided the discharge period was less than the time required for material to traverse the electrode dimension. By using various values of the transverse magnetic field the rarefaction and compression (shock) behavior of the plasma established between the electrodes could be determined and the ohmic heating and magnetic driving energies specified. The impulse tube is a potential tool for studying the plasma equation of state and conductivity.

**IA10. Measurement of the Temperature and Density Ratio across Strong Shocks in Hydrogen.*** WOLFGANG WIESE,† H. F. BERG, AND H. R. GRIEM, *University of Maryland.*—Mach 45 shocks were produced in a magnetic shock tube and the line and continuum radiation emitted by the shock-heated plasma was observed spectroscopically. The temperature was determined from total line intensities using a modified Fowler-Milne method and the electron density from continuous intensities and line profiles using Stark broadening theory. The measured temperatures and electron densities indicate almost complete ionization and are in disagreement with the values expected from usual shock theory. As in helium[1,2] the temperatures are too high and the densities too low. Again much better agreement can be obtained, if one assumes that the shock is moving into a medium consisting mainly of excited atoms.

* Jointly sponsored by GRDC and Office of Naval Research.
† Now at the National Bureau of Standards.
[1] E. A. McLean, C. E. Faneuff, and H. R. Griem, Bull. Am. Phys. Soc. Ser. II, 5, 42 (1960).
[2] W. Wiese *et al.*, Bull. Am. Phys. Soc. Ser. II, 5, 316 (1960), this issue.

**IA11. Streak Camera Studies of Exploding Wires.** D. D. SHEAR, H. S. BURDEN, AND F. D. BENNETT, *Ballistic Research Laboratories.*—A streak camera with transverse backlighting of the axisymmetric disturbance is described. With a four-sided mirror rotating at 1800 rps and an optical lever arm of 1 m, resolving times as low as 10 mμsec are possible. Flash backlighting of approximately 20 μsec is obtained from a BH-6 mercury-tube pulsed by suitable LC network. The optics are arranged so that most of the direct light from the disturbance falls outside the limiting aperture of the mirror. Photographs are shown of 4 and 5 mil Cu wires exploded at energies of about 20 joules/cm. With the above time resolution a nearly linear expansion of the wires can be clearly seen in an interval of 40–60 mμsec prior to the explosion which ultimately causes the luminous shock wave. The shock can be seen separating from metal vapor about 1 μsec later. Numerous weak compressive disturbances can be seen inside the main shock wave at later times.

**IA12. Electrical Measurements of Exploding Wire Phenomena.** H. S. BURDEN, D. D. SHEAR, AND F. D. BENNETT, *Ballistic Research Laboratories.*—Simultaneous measurements of current, voltage, and light output have been obtained for typical explosions of 4 and 5 mil Cu wires. A description is given of the shunt and the voltage divider used, and precautions taken to minimize or account for the effects of inductance. A simple photocell circuit with response time of about 0.04 μsec is used to observe the total light given off by the explosion. If one assumes that an observed sudden rise in light output coincides with the beginning of the luminous flash observed on the backlighted streak pictures, then electrical and optical data may be correlated in time. Inferences made from this correlation of data will be discussed. Power consumption in the wire may be obtained from the current and voltage records. By numerical integration energy deposited in the wire as a function of time may be deduced. For the examples given this curve seems to be representable by a simple power law in time.

**IA13. Relation between Energy Input and Shock Development for Exploding Wires.** F. D. BENNETT, H. S. BURDEN, AND D. D. SHEAR, *Ballistic Research Laboratories.*—Combined electrical and optical measurements of an exploding wire allow a test to be made of the hypothesis that the shock wave follows the trajectory predicted for a similarity flow with variable energy addition. According to the similarity flow theory developed by Guderley and others, similarity solutions may be obtained when axial energy release to the flow is given by a power law of time with exponent $(4/n)-2$. When $n=2$ the energy addition is independent of time and occurs at $t=0$. Under these conditions the shock trajectory is a parabola. Previous investigations have always shown deviations of the real shock from a parabola and therefore indicate values of $n$ other than 2. Comparisons are now possible between the time dependence of energy release both as determined from the shock trajectory and from the electrical measurements. The possibility that the outer portions of the flow field show the appropriate similarity will be discussed.

TUESDAY MORNING AT 10:00

Exhibit Hall

(R. K. WANGSNESS presiding)

## *Paramagnetic Resonance*

**J1. Electron Spin Paramagnetic Resonance (ESPR) of Irradiated Single Crystals of LiF.*** Y. W. KIM, R. KAPLAN, AND P. J. BRAY, *Brown University.*—Thermal annealing has been found to change the width and Gaussian shape of the previously reported ESPR spectrum of irradiated LiF.[1–3] The angular dependence of the remaining hyperfine structure upon annealing appears to be the same as before annealing. Similar angular variation of the hyperfine structure has also been observed together with Lorentzian envelopes of various widths from heavily irradiated LiF. It is very likely that two essentially independent centers are contributing to the charteristic ESPR hyperfine spectrum of neutron-irradiated LiF. Under certain conditions, the dipolar terms of the next nearest (fluorine) shell of Seitz's *F* center in LiF give a scheme of hyperfine levels whose angular dependence is similar to that observed. Other models for the two centers assumed to be responsible for the observed spectrum will be discussed.

* Work supported by the U. S. Atomic Energy Commission.
[1] Y. W. Kim, R. Kaplan, and P. J. Bray, Bull. Am. Phys. Soc. Ser. II, **3**, 178 (1958).
[2] Y. W. Kim, R. Kaplan, and P. J. Bray, Bull. Am. Phys. Soc. Ser. II, **4**, 261 (1959).
[3] P. J. Bray, Y. W. Kim, and R. Kaplan, 1959 International Symposium on Color Centers in Alkali Halides, Corvallis, Oregon.

**J2. Electron Spin Resonance of X Irradiated β-Succinic Acid.*** C. HELLER† AND H. M. MCCONNELL, *California Institute of Technology.*—The electron spin resonance spectrum of single crystals of β-succinic acid irradiated with 50-kv x rays has been observed at 9500 Mc. The main long-lived species produced at room temperature is found to be an oriented $(CO_2H)\dot{C}H_2CH(COOH)$ radical. One of the hyperfine interactions found in this radical is strongly anisotropic and nearly the same as previously found for $(CO_2H)\dot{C}H(COOH)$ in irradiated malonic acid.[1] This interaction is attributed to the proton directly bonded to the carbon atom on which the odd electron is largely localized. The two methylene protons in the succinic acid radical are shown to be not equivalent: their hyperfine interactions are almost isotropic, but different, and in the range of 80–100 Mc.

* Sponsored by the Office of Ordnance Research, U. S. Army, the National Science Foundation, and the United States Public Health Service.
† Now at Scientific Laboratory, Ford Motor Company, Dearborn, Michigan.
[1] McConnel, Heller, Cole, and Fessenden, J. Am. Chem. Soc. (in press); Proc. Natl. Acad. Sci. **45**, 525 (1959).

**J3. Paramagnetic Resonance of $Cr^{3+}$ in Yttrium Gallium Garnet.** S. GESCHWIND AND J. W. NIELSEN, *Bell Telephone Laboratories.*—Paramagnetic resonance of a small $Cr^{3+}$ impurity in $3Y_2O_3 \cdot 5Ga_4O_3$(YGaG) has been studied at 24 kMc at room temperature. The $Cr^{3+}$ enters substitutionally for the $Ga^{3+}$ in the octahedral sites only. No evidence of $Cr^{3+}$ in the tetrahedral sites was found. The strength of the resonance signal indicates that the $Cr^{3+}$ is far less soluble than $Fe^{3+}$ in this lattice. The axial crystal field parameter $D$ for $Cr^{3+}$ associated with the axial distortion in the octahedral site was found to be $D = +10\,506 \pm 1$ Mc with $g_{\parallel} = 1.9767 \pm 0.002$ and $g_{\perp} = 1.9757 \pm 0.002$. The fact that $D$ for $Cr^{3+}$ is twice as large in YGaG as in $Al_2O_3$ and opposite in sign will be discussed in terms of the crystal fields in the two lattices.

**J4. Ratio of Secular to Nonsecular Broadening for Exchange-Narrowed Paramagnetic Resonances.*** G. E. PAKE, *Stanford University.*—When the frequency of paramagnetic resonance is less that the correlation frequency describing the random modulation of the interactions responsible for line broadening, there are additional "nonsecular" contributions to the line width.[1] For dipolar interactions, a motionally or exchange-narrowed line is broadened to 10/3 of its secular width (10/3 effect[2]). Calculations are presented which show that, if appreciable hyperfine interaction is present, the ratio departs[3] from 10/3. Values of the ratio will be given in terms of the relative amounts of isotropic and anisotropic hyperfine coupling; for purely isotropic coupling it is 2. Comparisons will be made with the measurements of Rogers, Anderson, and Pake[4] on solutions of stable free radicals.

* Supported by the Air Force Office of Scientific Research.
[1] R. Kubo and K. Tomita, J. Phys. Soc. Japan **9**, 888 (1954).
[2] P. W. Anderson and P. R. Weiss, Revs. Modern Phys. **25**, 269 (1953).
[3] D. Kivelson (private communication) has reached this conclusion independently.
[4] R. N. Rogers, M. E. Anderson, and G. E. Pake, Bull. Am. Phys. Soc. Ser. II, **4**, 261 (1959).

**J5. Paramagnetic Resonance Line Shapes of Powders, Glasses, and Viscous Solutions Containing Unpaired Spins with Anisotropic *g* Factors.** F. K. KNEUBUHL AND W. S. KOSKI, *The Johns Hopkins University.*—The line shapes arising from randomly oriented particles in a fixed position have been calculated. It is found that it is theoretically possible to determine the 3 principal $g$ factors with relatively high accuracy without investigating single crystals. Measurements on powders of $CuCl_2 \cdot 2H_2O$ and $CuSO_4 \cdot 5H_2O$ are used for demonstration. Other examples are mentioned. In addition, the influence of Brownian rotation is viscous liquids on line shapes of the same type has been studied. Equations have been derived for the case of high viscosities, supplementing the well-known ones given by McConnell.[1] To a first approximation, the effect of decreasing viscosity can be described by over-all diminishing line width and an unchanged line shape. Experimental results will be discussed. The hyperfine splittings are neglected in all considerations, but they can be taken into account.

[1] H. M. McConnell, J. Chem. Phys. **25**, 709 (1956).

**J6. Application of a Reduced Relativistic Wave Equation* to Spin-Lattice Relaxation in Paramagnetic Salts.** R. J. PENDERGAST AND W. A. BARKER, *St. Louis University.*—As yet, no fully satisfactory theoretical treatment of spin-lattice relaxation in paramagnetic salts has been given. The object of the present work was to investigate more exhaustively than before possible relaxation mechanisms involving the interaction of one ion only with the lattice. To this end augmented relativistic one- and two-body wave equations were reduced to approximate form[1] and the resulting terms combined in various ways. Those mechanisms which order of magnitude estimates indicated would be stronger were calculated more exactly for titanium and chrome alum, following the work of Van Vleck.[2] The shortest relaxation time found exceeds the experimental value by $10^4$ and has the same incorrect field dependence as Van Vleck's. It seems, therefore, that unexplained features of spin-lattice relaxation are not due to any overlooked mechanism involving the interaction of only one ion with the lattice.

* Work supported in part by National Science Foundation and U. S. Air Force Office of Scientific Research.
[1] W. A. Barker, Bull. Am. Phys. Soc. Ser. II, **2**, 263 (1957).
[2] J. H. Van Vleck, Phys. Rev. **57**, 426 (1940); **57**, 1052 (1940).

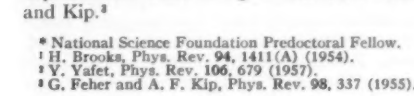
**J7. Paramagnetic Relaxation of $VO^{++}$ Ion.*** R. N. ROGERS, *Stanford University.*—Previous paramagnetic resonance studies of $VO^{++}$ ion in solutions have revealed a hyperfine structure whose component line widths vary with $m_I$.[1] McConnell has proposed a mechanism to explain this variation based on the assumption that the ion is contained in a randomly tumbling "microcrystallite," and has shown thereby a possible mechanism in which part of the relaxation is dependent on $m_I$ and on the anisotropic hyperfine constant.[2] The measurements to be reported were made to determine the validity of the model. By comparing the line widths measured at 9.25 and 24.3 kMc with calculations made by Kivelson[3] incorporating McConnell's results, reasonable agreement is obtained, indicating the validity of the microcrystallite model.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research.
[1] G. E. Pake and R. H. Sands, Phys. Rev. **98**, 266 (1955).
[2] H. M. McConnell, J. Chem. Phys. **25**, 709 (1956).
[3] D. Kivelson (private communication).

**J8. $g$ Factor in Alkali Metal Conduction Electron Spin Resonance.** ARTHUR BIENENSTOCK* AND HARVEY BROOKS, *Harvard University.*—A quantitative theory of the $g$ factor in alkali metals has been developed which permits calculations based only on a knowledge of the spectroscopic term values of the free atom, including the fine structure intervals. The method is based on an extension, discussed by Brooks,[1] of the quantum defect method and Yafet's theory of the $g$ factor.[2] The numerical results for all the alkali metals have been obtained as a function of the radius of the Wigner-Seitz sphere. The result for sodium, $r_S=3.99$, is compared to the experimental value of $\Delta g=-8\pm2\times10^{-4}$ obtained by Feher and Kip.[3]

* National Science Foundation Predoctoral Fellow.
[1] H. Brooks, Phys. Rev. **94**, 1411(A) (1954).
[2] Y. Yafet, Phys. Rev. **106**, 679 (1957).
[3] G. Feher and A. F. Kip, Phys. Rev. **98**, 337 (1955).

**J9. Electron Spin Resonance in an Gamma Irradiated Single Crystal of L-Cystine Dihydrochloride.*** YUKIO KURITA† AND WALTER GORDY, *Duke University.*—The electron spin



has been measured at 9 kMc/sec and at 24 kMc/sec for various orientations of the crystal in the magnetic field. The resonance pattern was found to be a doublet, the spacing between the components of which is independent of the crystal orientation as well as of the strength of the static magnetic field. The spectroscopic splitting factor was found to be anistotopic with the principal values: $g_1=2.0035$, $g_2=2.0249$, and $g_3=2.0534$. A model of the free radical, in which the electron spin density is mainly concentrated in a nonbonding orbital of sulfur atom, is proposed. The model accounts very well for the principal values of the $g$ tensor as well as their directions relative to the atomic configuration.

* This work was supported by the U. S. Air Force Office of Scientific Research.
† International Exchange Fellow.

**J10. Electron Spin Resonance of Gamma Irradiated Single Crystals of Normal and Deuterated Glycine.*** MIKIO KATAYAMA AND WALTER GORDY, *Duke University.*—A single crystal of normal glycine and one in which the $NH_2$ and OH protons are replaced by deuterium have been gamma irradiated and the electron spin resonance of the radiation induced free radicals observed for various orientations in the magnetic field. The marked difference of the resonance patterns of the two forms proved that the liable protons of the amino group form part of the free radical. Because of its small moment, structure arising from D coupling is unresolved in the $D_2O$ treated crystal and for some orientations a simple triplet apparently arising from the $CH_2$ group of the radical is observed. However, we could not observe $N^{14}$ coupling reported by Ghosh and Whiffen[1] on normal glycine. From the combined results in normal and deuterated glycine it is concluded that the probable form of the free radical observed is $CH_2NH_2$. The analysis is not yet complete and this assignment of the free radical is tentative.

* This work was supported by the Office of Ordnance Research, Department of the Army.
[1] D. K. Ghosh and D. H. Whiffen, Mol. Phys. **2**, 285 (1959).

**J11. $D$ vs $eQq/h$ in Alums and GASHs.** GERALD BURNS, *IBM Research Laboratory, Poughkeepsie.*—One can measure the temperature dependence of $eQq/h$ of Al in an alum. Also small amounts of Cr can be substituted in the alum and the temperature dependence of the electron spin resonance can be measured. One can then eliminate temperature and study the relationship between $D$ and $eQq/h$. This has been done for the $\alpha$ alums, $XAl(SO_4)_2\cdot12H_2O$(X=Rb, Tl, $NH_4$, and K), the $\beta$ alums, $YAl(SO_4)_2\cdot12H_2O$(Y=Cs and $CH_3NH_3$), and the two nonequivalent sites in the four crystals $C(NH_2)_3Z(WO_4)_2\cdot6H_2O$(Z=Al and Ga, W=S and Se). $D$ vs $eQq/h$ shows that all four $\alpha$ alums fit on a ***single line***, $D=\gamma(eQq/h)+\Delta$ with $\gamma=2.7\times10^{-4}$ cm$^{-1}$ (kc)$^{-1}$ and $\Delta=-0.072$ cm$^{-1}$. Similarly, the two $\beta$ alums fit on a line with $\gamma=8\times10^{-5}$ cm$^{-1}$ (kc)$^{-1}$ and $\Delta=+0.063$ cm$^{-1}$. For the GASH type crystals with Al, the coefficients are $\gamma=2.6\times10^{-4}$ cm$^{-1}$ (kc)$^{-1}$ and $\Delta=0.067$ cm$^{-1}$. The line for the Ga compounds is parallel to the Al compounds (provided the difference between $Q$ and the antishielding factors are considered) but displaced to larger $D$ so that the intercept is 0.11 cm$^{-1}$. The intercept is probably an indication of the distortion around the Cr ion. Assuming only that the axial potential $=Ar^2Y_2^0$, one can understand a linear relation between $D$ and $eQq/h$. However, the calculated value of $\gamma$ is $1.6\times10^{-5}$ cm$^{-1}$ (kc)$^{-1}$. A calculation of the extra potential due to distortion of the ion core (similar to an antishielding factor calculation) did not alter the result significantly.

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TUESDAY MORNING AT 10:00

Adams-Hamilton Room

(R. W. HAYWARD presiding)

## *Radioactive Nuclei II*

**JA1. Angular Correlation Measurements on $\gamma$-$\gamma$ Cascades in $Pd^{104}$, $Pd^{108}$, and $Zn^{66}$.*** M. E. BUNKER AND J. W. STARNER, *Los Alamos Scientific Laboratory.*—We have studied the angular correlation of the following $\gamma$-$\gamma$ cascades: (1.24–0.56) Mev in $Pd^{104}$, (0.62–0.43) Mev in $Pd^{108}$, and (0.83–1.04) Mev in $Zn^{66}$. The radioactive sources used in these experiments

were 42-sec $Rh^{104}$ (in equilibrium with 4.4-min $Rh^{104m}$), 2.3-min $Ag^{108}$, and 5.1-min $Cu^{66}$, respectively. Our data indicate that both the 1.80-Mev level in $Pd^{104}$ and the 1.05-Mev level in $Pd^{108}$ are 0+ states. No evidence has been found for the reported[1] 1.8-Mev cross-over transition in $Pd^{104}$. The $Zn^{66}$ angular correlation is of the type $2(D,Q)2(Q)0$, with the upper transition having an $E2/M1$ ratio of 5.1. The cross-over transition to the $Zn^{66}$ ground state has not been observed; an upper limit for the branching ratio (cross over/cascade) of the 1.87-Mev, 2+ level is 0.03.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. K. Girgis and R. Van Lieshout, Nuclear Phys. 13, 493 (1959).

**JA2. Decay of $Ba^{133}$.*** W. L. SKEEL, M. K. RAMASWAMY, AND P. S. JASTRAM, *The Ohio State University.*—The gamma rays following the electron-capture decay of 7.5-year $Ba^{133}$ have been studied by means of a coincidence scintillation spectrometer. Gamma rays at 79, 79, 274, 302, and 358 kev have been observed. In addition, the presence of gamma rays at 56 and 381 kev has been confirmed. The resulting decay scheme with levels at $79(5/2^+)$, $158(5/2^+)$, $381(3/2^+)$ and $438(1/2^+)$ kev is in excellent agreement with previous work. Results of a determination of the decay energy will be presented.

* Supported by the U. S. Atomic Energy Commission.

**JA3. Shape of the Beta Spectra of $La^{140}$ and $Sb^{124}$.*** L. M. LANGER AND D. R. SMITH, *Indiana University.*—The beta spectrum of the highest energy transition in the decay of $La^{140}$ is found to have a nonunique, nonstatistical shape. The data can be fitted with a shape factor $C\sim(W_0-W)^2+10\pm5$ from $W=4.3$ to the endpoint at $W_0=5.258m_0c^2$. The shape is consistent with a 3− to 2+ transition and eliminates the possibility of 4− for the ground state of $La^{140}$. The data on the highest energy group of $Sb^{124}$ have been reanalyzed in a manner suggesting the dominance of the $B_{ij}$ matrix element.[1] The data above $W=4.2$ are fitted by a shape factor $(W_0-W)^2+0.874(W^2-1)+15\pm5$ with $W_0=5.534m_0c^2$. This fit is consistent with the earlier interpretation[2] of the decay as once forbidden from a 3− level in $Sb^{124}$ to the 2+ level in $Te^{124}$.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] T. Kotani, Phys. Rev. 114, 795 (1959).
[2] L. M. Langer, N. H. Lazar, and R. J. D. Moffat, Phys. Rev. 91, 338 (1953).

**JA4. Beta Spectrum of $Eu^{156}$.*** D. R. SMITH, L. M. LANGER, AND D. A. HOWE, *Indiana University.*—$Eu^{156}$ was produced by multiple neutron capture in 95% enriched $Eu^{153}$. The beta spectrum above the end point of $Eu^{154}$ was studied in a magnetic spectrometer. The high comparative half-life associated with the decay suggests that the spectrum groups might have nonunique, nonstatistical shapes, dominated by the $B_{ij}$ matrix element. On this assumption, the high-energy beta distribution can be resolved into groups with end point energies at 2.50 Mev and 2.30 Mev corresponding to transitions from 3− ground state in $Eu^{156}$ to the 2+ level at 89 kev and the 4+ level at 285 kev in $Gd^{156}$.[1] The relative intensity of the 2.50-Mev and 2.30-Mev transitions is ∼7:1 corresponding to log$ft$ values of ∼9.9 and ∼10.5, respectively, on the assumption that these two groups account for ∼40% of the total beta transitions.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] G. T. Ewan, R. L. Graham, and J. S. Geiger, Bull. Am. Phys. Soc. Ser. II, 5, 21 (1960).

**JA5. Decay of $Eu^{146}$.** E. G. FUNK, C. F. SCHWERDTFEGER, AND J. W. MIHELICH, *University of Notre Dame,** AND B. HARMATZ, *Oak Ridge National Laboratory.*†—$Eu^{146}$ (5.1 days) was produced by proton bombardment of enriched $Sm^{147}$ in the ORNL 86-in. cyclotron. The decay of $Eu^{146}$ to $Sm^{146}$ proceeds by electron capture (90%) and positron emission (10%). Gamma transitions of 635, 667, 749, 902, 1301, and 1536 kev were observed with both permanent magnet spectrographs and scintillation counters. In addition, a very complex spectrum of gamma rays of energies from about 1.0 to 2.5 Mev was observed. On the basis of gamma-gamma coincidence measurements and transition energies, levels at 749, 1384, 2051, and 2286 kev in $Sm^{146}$ are postulated. Coincidences with 749-kev gamma rays indicate levels up to about 3.3 Mev. The existence of positrons was verified by absorption measurements, scintillation spectrometry of the positrons, and triple coincidence measurements involving annihilation quanta. The majority of the positrons (of approximate energy 1190 and 960 kev) feed the levels at 2051 and 2286 kev indicating an available energy of about 4.3 Mev for the $Eu^{146}$ decay. Gamma-gamma directional correlation measurements were carried out on the prominent cascades. The interpretation was difficult due to interference from competing cascades. It seems certain that the 1384 kev level cannot be of 4+ character. Possible spin assignments for this and other levels will be discussed.

* Supported by the U. S. Atomic Energy Commission.
† Operated for the U. S. Atomic Energy Commission by the Union Carbide Corporation.

**JA6. Beta-Gamma Angular Correlation in the Decay of $Eu^{152}$.*** R. G. WILKINSON AND H. J. FISCHBECK, *Indiana University.*—The directional correlation between the first forbidden nonunique outer beta-ray group of $Eu^{152}$ and the 0.344-Mev cascade gamma ray in $Gd^{152}$ has been measured at eleven beta-ray energies with an accuracy of 5% or better. Measurements were made with a small shaped magnetic field beta-gamma coincidence spectrometer having 5% transmission, 5% energy resolution, and a coincidence resolving time of 40 mμsec. The experimental results are in good agreement with the "modified $B_{ij}$ approximation" of the theory of Kotani and Ross,[1] as it applies to a $3(\beta)2(\gamma)0$ first forbidden transition. The quantity $Y$, which in their notation is the ratio of a linear combination of three matrix elements to $B_{ij}$, is found to be $0.69\pm0.06$. This is to be compared with the value $Y=0.64\pm0.14$, which can be obtained from Langer's measured shape factor, once the appropriateness of the modified $B_{ij}$ approximation has been established.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] T. Kotani and M. Ross, Progr. Theoret. Phys. (Kyoto) 20, 643 (1958).

**JA7. Decay Studies of $Dy^{155}$ and $Dy^{157}$.** KENNETH S. TOTH* AND O. B. NIELSEN, *Institute for Theoretical Physics, Copenhagen.*—Levels in $Tb^{155}$ and $Tb^{157}$ populated in the decay of $Dy^{155}$ and $Dy^{157}$, respectively, have been investigated. The two dysprosium nuclides were produced by $(\alpha,n)$ reactions on $Gd^{152}(Dy^{155})$ and $Gd^{154}(Dy^{157})$, utilizing alpha particles accelerated in the Copenhagen cyclotron. A six-gap beta-ray spectrometer was used (1) to obtain conversion electron spectra, and (2) in conjunction with a 100-channel scintillation spectrometer to perform $e$-$\gamma$ coincidence measurements. In the case of $Dy^{157}$ the coincidence experiments were sufficient to confirm the decay scheme proposed by Michelich *et al.*[1] Their disintegration scheme is based on differences and sums of accurately determined transition energies. Our $Dy^{155}$ $e$-$\gamma$ measurements were not so definitive. However, the results obtained agree with earlier work concerning the conversion-electron spectrum of $Dy^{155}$.[2] The data indicate the low-energy level structures of $Tb^{155}$ (90 neutrons) and $Tb^{157}$ (92 neutrons) to be quite similar, as might be expected for two nonspherical nuclei differing only by a pair of neutrons.

* Present address: Oak Ridge National Laboratory.
[1] J. W. Michelich, B. Harmatz, and T. H. Handley, Phys. Rev. 108, 989 (1957).
[2] K. S. Toth and J. O. Rasmussen, Phys. Rev. 115, 150 (1959).

**JA8. Unexpected 3/2- Intrinsic State in $Ho^{165}$.*** F. P. CRANSTON, JR., M. E. BUNKER, AND J. W. STARNER, *Los Alamos Scientific Laboratory.*—We have found that the principal beta transition ($E_\beta$=0.87 Mev) to $Ho^{165}$ from 1.25-min $Dy^{165m}$ has a log*ft* value of 5.2. This result, coupled with certain well-established facts regarding the decay schemes of the two $Dy^{165}$ isomers, leads to the conclusion that the 0.516-Mev excited state in $Ho^{165}$ populated by the above beta transition is an intrinsic state with spin and parity of 3/2−. Examination of the Nilsson energy level diagram reveals that no low-lying 3/2− excited states are expected in a 67-proton nucleus. In addition, there is no experimental evidence for the occurrence of a 3/2− intrinsic state in any other odd-*Z* nucleus in the 61–75 proton region. The possibility that the observed 3/2− level is a Nilsson intrinsic state associated with shell-model states above *Z*=82 will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**JA9. Levels in the Odd-Odd Nucleus $_{67}Ho^{166}$.** J. S. GEIGER, R. L. GRAHAM, AND G. T. EWAN, *Atomic Energy of Canada Limited, Chalk River.*—The disintegration scheme of $Dy^{166}$ is being investigated using the Chalk River precision $\beta$-ray spectrometer, scintillation spectrometers, and coincidence counting techniques. The conversion electron spectrum has been surveyed in the energy range 10–310 kev at a momentum resolution setting of ~0.15%. The 28 conversion lines observed have been identified with transitions in $Ho^{166}$ of 28.21 kev, *M*1 with <1% *E*2; 54.21 kev, *E*2 with <25% *M*1; 82.42 kev, *M*1 with <1% E2; and with the 80.54 kev *E*2 transition in $Er^{166}$. The above transition multipolarities result from comparison of the observed conversion line intensity ratios with the theoretically predicted values of Sliv. Scintillation $\gamma$-ray spectra indicate two additional transitions in $Ho^{166}$ of energies 385±10 and 440±10 kev having quantum intensities $I_{440}/I_{385}/I_{82.42}=0.08_0/0.06_7/1$. Conversion-electron gamma coincidence measurements show that the 385-kev transition is in coincidence with the 54.21-kev transition. The 440-kev transition is not in coincidence with either the 54.21- or 82.42-kev transitions. The above results, togehter with the 0− ground state spin assignment for $Ho^{166}$ from earlier work indicate levels in $Ho^{166}$ of O kev 0−; 54.21 kev 2−; 82.42 kev 1−; and 440 kev 1(+). The relative quantum transition intensities of the *M*1 transitions de-exciting the 82.42-kev level are in agreement with a *K*=0 assignment to the 0−, 2−, and 1− levels.

**JA10. Radioactive Decay of $Tm^{166}$ and $Tm^{168}$.** R. G. WILSON AND M. L. POOL, *Ohio State University.*—Samples of erbium oxide enriched in the 166 and 168 mass numbers were irradiated with 6-Mev protons. $Tm^{166}$ (7.69±0.04 hr) was produced and observed to consist of the erbium *K* x ray, gamma rays with energies of 81, 184, 215, 285, 405, 460, 600, 675, 695, 705, 760, 780, 785, 880, 1050, 1175, 1275, 1350, 1870, and 2055 kev, annihilation radiation, and 2.09-Mev particle radiation. Gamma-gamma coincidence measurements have led to the assignment or confirmation of levels at 81(2+), 265(4+), 554(6+), 788(2+), 863(3+), 959(4+), 1258(3), 1462(2), 1547(3+), 1701(4+), 1894(5+), 2139(3−), and 2168(0) kev in $Er^{166}$ using the previously published conversion electron energies. The 2139-kev level is highly populated by electron capture and the positron transitions occur to the 265-kev level which places the ground state of $Tm^{166}$, to which the predicted spin of 3− is assigned, at 3375 kev above the ground state of $Er^{166}$. $Tm^{168}$ (85±3 days) was observed to consist of the erbium *K* x ray and gamma rays with energies of 80, 100, 185, 200, 285, 445, 450, 550, 630, 650, 725, 730, 740, 815, 820, 830, 1015, 1280, and 1465 kev. Gamma-gamma coincidence measurements have led to the assignment or confirmation of levels at 80(2+), 265(4+), 550(6+), 820(2+), 895(3+), 995(4+), 1095(3+), and 1545(3−) kev in $Er^{168}$. The electron capture transitions from $Tm^{168}$, to which is assigned the predicted spin of 3+, occur primarily to the 1095- and 1545-kev levels. The positions and relative numbers of the observed radiations and branching ratios for electron capture are shown in proposed energy level schemes.

**JA11. Radioactive Decay of $Hf^{172}$, $Hf^{173}$, and $Tm^{167}$.** H. NARASIMHAIAH AND M. L. POOL, *Ohio State University.*—Ytterbium oxide eneriched in the mass number 170 was irradiated with 24-Mev alpha particles. An activity consisting of the *LuK* x ray and gamma rays with energies of 80 and 123 Kev was found to decay with a long half-life and assigned to $Hf^{172}$. The two gamma rays are not in coincidence. The relative intensities of the *LuK* x ray: 80-Kev gamma ray: 123-Kev gamma ray =100:12:16. An energy level scheme has been drawn. Following the irradiation of ytterbium oxide enriched in the mass number 171 an activity consisting of the *LuK* x ray and gamma rays with energies of 123, 135, 162, 297, 540, 720, 880, 1030, 1200, and 1450 Kev decaying with a half-life of 24 hr was assigned to $Hf^{173}$. From the relative intensities of the gamma rays and the coincidence measurements an energy level diagram can be formulated. An activity with the *ErK* x ray and gamma rays with energies of 57, 207, and 534 Kev decaying with a half-life of 9.7 days was assigned to $Tm^{167}$ following a deuteron bombardment of erbium oxide enriched in the mass number 167. None of the gamma rays are in prompt coincidence.

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## TUESDAY MORNING AT 10:00

## Burgundy Room

## (S. B. TREIMAN presiding)

### *Theoretical Physics II: Particle Theory*

**K1. Vector Model in the Elementary Particles.*** KIU S. SUH, *Cornell University.*—Baryon and strangeness vectors are introduced with a one-half as the basic unit, and the origin of the isotopic spin is argued to be merely the consequence of the vector addition involved in establishing the charge vector from these two newly defined vectors. The charge vector in our model is exhibited to have the property in the intrinsic world similar to that of the magnetic moment in the spacial world. The possible implications of this model with respect to the mass spectrum of the elementary particles and the meaning of the global symmetry are discussed. Attempts are also made in predicting the experimentally observed resonances in strong interactions and the selection rules on isotopic spin and strangeness in weak decays.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**K2. Effect of Final State Interactions on $\Lambda^0$ and $\Sigma^0$ Hyperon Production from ($\Sigma^-$,$D$) Capture Reactions.*** YUNG Y. CHEN, *University of Maryland* (sponsored by G. A. Snow.)—The effects of the two neutron final state interaction in the reaction $\Sigma^-+D\rightarrow(\Lambda^0 \text{ or } \Sigma^0)+n+n$ is calculated using the impulse approximation and the assumption of $S$ wave absorption. Comparing these results with those of Day, Snow, and Sucher,[1] who neglected all final state interactions, one finds that the $\Sigma^0$ production can be enhanced by a factor $\sim$5 while the $\Lambda^0$ production is increased by only $\sim$10%. The experimental results on the $\Sigma^0/\Lambda^0$ ratio of Dahl *et al.*[2] can now be fit with a less extreme assumption about the spin dependence of the transition matrix for the reaction $\Sigma^-+p\rightarrow\Sigma^0+n$, although an appreciable amount of spin dependence is still required. The momentum spectra of the $\Sigma^0$ and $\Lambda^0$ hyperons will also be discussed.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] T. B. Day, G. A. Snow, and J. Sucher, Phys. Rev. Letters 2, 468 (1959).
[2] O. Dahl, N. Horwitz, D. Miller, and J. Murray, Phys. Rev. Letters 4, 77 (1960).

**K3. Interaction of Charged Particles with a Quantized Field.*** LEO P. KADANOFF AND ROY J. GLAUBER, *Harvard University.*—The interaction between a nonrelativistic electron and the electric field within a cavity that has but a single mode of oscillation has been considered as a problem in quantum electrodynamices. If the energy of the incident electron is sufficiently high, an approximate S matrix can be found by using the high-energy approximation.[1] The energy spectra of electrons emerging from the cavity are discussed for experiments in which no measurements are made on the final state of the cavity. The quantum mechanical measurement process can be illustrated by discussing the spectra for certain limiting forms of the initial cavity states and electron wave packets. The spectra, their mean values, and central moments are stated explicitly. For the particular case in which the initial electron energy is precisely defined, we show explicityly how the line spectrum becomes related to the classical continuum as the average number of quanta exchanged with the cavity increases. The classical continuum results from the smoothing of a line spectrum in which the intensities vary quite irregularly. The line intensities decay exponentially in the classically forbidden regions of energy transfer.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] R. J. Glauber, *Lectures in Theoretical Physics* (Interscience Publishers, Inc., New York, 1959), Vol. I, p. 315.

**K4. Bose Currents in the Theory of Weak Interactions.*** W. B. ZELENY† AND A. O. BARUT, *Syracuse University.*—A possible new method of introducing Bose currents into the weak interaction is suggested. The Bose fields are assumed to obey the first order Kemmer equation. In this way, the Bose and Fermi currents enter into the interaction in a symmetric manner. Three coupling constants are introduced according to the degree of isotipic spin and strangeness symmetries of the currents. The interactions so obtained contain the $|\Delta T|=\frac{1}{2}$ rule, and correctly give rise to (a) fast pionic and slow leptonic modes of hyperon decay, (b) a violation of the $|\Delta T|=\frac{1}{2}$ rule of the right order of magnitude, and (c) slow $K_{e3}$ and $K_{\mu 3}$ decays, in contrast to the results of Sugawara.[1] Several numerical results will be presented.

* Supported in part by the U. S. Air Force Office of Scientific Research.
† National Science Foundation Cooperative Graduate Fellow.
[1] M. Sugawara, Phys. Rev. 112, 2128 (1958); 113, 1361 (1959).

**K5. Polarization Effects in the Scattering of Initially Unpolarized Electrons and Muons.** A. O. BARUT,* *Syracuse University*, C. FRONSDAL, AND A. PETERMAN, *CERN.*—It may be experimentally feasible, in the future, to measure the polarization of high-energy electrons or muons in $e$-$e$, $e$-$\mu$, or perhaps even $\mu$-$\mu$ scatterings. The problem is also of some theoretical interest and the calculation of the effect does not involve any renormalization or cutoff. To the second order there is no polarization since the matrix element is real. Results of the lowest order calculations of polarization will be presented which involve the product of the second and the imaginary part of the fourth-order martix elements. The latter is evaluated directly and also from the unitarity condition.

* Supported in part by the U. S. Air Force Office of Scientific Research.

**K6. Radiative Corrections to the Electron-Electron Scattering.*** YUNG SU TSAI, *Stanford University.*—Radiative corrections to $e$-$e$ scattering are calculated assuming the following experimental conditions. The experiment, being performed by O'Neill *et al.* at Stanford, is done with a two intersecting 500-Mev electron beams and is designed to test the validity of quantum electrodynamics at small distances down to $\sim 0.5\times10^{-14}$ cm. The detectors for scattered electrons are Čerenkov counters facing each other with equal circular apertures extending the same solid angle and arranged for coincidence. Čerenkov counters are assumed to have no energy resolution. Angular distributions from 35° to 90° are taken. The two-photon exchange diagrams (crisscross and noncrisscross) contribute negligible to the cross section ($<0.1\%$) after cancellation with the corresponding soft real photon contribution. Hence the soft real photon plus the elastic cross sections are essentially the same as Schwinger's corrections to the electron nucleus scattering with contributions from bremsstrahlung and vertex parts doubled but the vacuum polarization term undoubled. Assuming the half-angle of the counter to be 3.5°, the radiative corrections to the Møller cross section are found to be $-8.1\%$ and $-4.8\%$ at $\theta$ equal to 90° and 35°, respectively. Mesonic effects in the vacuum polarization are also calculated and found to be negligible.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research.

**K7. Radiative Corrections to Muon and Neutron Decay.*** L. DURAND, III, L. F. LANDOVITZ, AND R. B. MARR, *Brookhaven National Laboratory.*—The electromagnetic corrections to muon and neutron decay, considered recently in perturbation theory by Kinoshita and Sirlin, have been re-examined using the techniques of dispersion theory. Integral equations relating the various invariant amplitude functions for the decays to the amplitudes for $\mu$-$\bar{e}$, and for $n$-$\bar{e}$ and $p$-$e$ scattering, follow from unitarity and assumed analyticity properties. This procedure permits the inclusion of the nucleon electromagnetic form factors in an unambiguous way. Electromagnetic effects coming from $n$-$p$ scattering can be absorbed in the strong coupling effects considered by Goldberger and Treiman. For the small $n$-$p$ momentum transfers $\Delta$ involved in beta decay, all dependence on $\Delta$ can be neglected. The strong coupling then acts merely to introduce effective coupling constants, which are used in an iterative solution of the integral equations correct to order $\alpha=1/137$. One subtraction is required in the dispersion relations for both muon and neutron decay. Inclusion of the nucleon form factors permits the use of unsubtracted dispersion relations in the terms coming from magnetic moment scattering, but, contrary to prior conjectures, does not do so for $e$-$p$ charge scattering. This is a consequence of the nonvanishing of the proton charge form factor for forward scattering, and is closely related to the problem of infrared divergences.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**K8. Decay of Bound Mu Mesons.** H. ÜBERALL, *Carnegie Institute of Technology.*—We have calculated the electron spectrum from the decay of muons bound in the $K$ shell of light point nuclei, accurate to the first power of $Z/137$, and

the muon decay lifetime to the second power. Relativistic wave functions are used, and the electron interaction with the nucleus is taken into account in appropriate (first and second) order. The lifetime is found to increase monotonically with $Z$, in apparent disagreement with experiments[1]; it is also found that the phase space factor $1-5(Z/137)^2/2$ is not a good representation of the theoretical $Z$ dependence of the decay rate. The effect of the extension of the nucleus on the spectrum has been evaluated numerically and is found to be small.

[1] R. A. Lundy, J. C. Sens, R. A. Swanson, V. L. Telegdi, and D. D. Yovanovitch, Phys. Rev. Letters 1, 102 (1958).

**K9. Collisional De-excitation of Mesic Atoms.** T. B. Day and L. S. Rodberg, *University of Maryland.*—The collision de-excitation of a mesic atom, following capture of the meson into a high atomic orbital, has been investigated using methods which maintain the unitarity of the $S$ matrix. Experiments in x ray yields in $\pi$- and $\mu$-mesic atoms, and measurements of the capture time of $\pi$ mesons in hydrogen bubble chambers, have suggested that de-excitation takes place through a fast nonradiative process. The usual plane-wave Born approximation is invalid for the low-energy collisions involved here. By including the unitary requirement one can obtain realistic cross sections for the various types of inelastic collisions which are possible (de-excitation by free electrons, atom-atom collisions, collisional Auger effects, etc.). A discussion of the rates of these various processes will be given.

**K10. Unstable Particle Production in a Soluble Model.*** E. Kazes, *The Pennsylvania State University.*—By using an interaction for which the only allowed elementary processes are $\psi_1 \rightleftarrows \psi_2+\varphi_2$, $\psi_1 \rightleftarrows \psi_3+\varphi_3$, $\psi_3 \rightleftarrows \psi_4+\varphi_4$, we adjust the cutoffs and bare masses so that there is no stable particle associated with the field $\psi_3$. The amplitude associated with the process $\psi_3+\varphi_2 \rightarrow \psi_3+\varphi_2$ when examined in coordinate space shows an exponential variation with respect to $r$ (the separation of $\psi_3 \propto \varphi_2$). This is associated with the decay of $\psi_3$ during the time that $\varphi_2$ travels the distance $r$. If the energy of $\varphi_2$ is not relativistic then exponential decay is found to be valid for a time $t$ such that

$$e^{-n/2} < \frac{1}{2\pi}\frac{\gamma^3}{(m_2+\omega_2-m_3-\mu_3)^3}\frac{1}{n^2},$$

where $n=t/\tau$ where $\gamma\tau=1$, and $\tau$ is the lifetime. Thus an unstable particle displays a memory of its production after a large time.

* Supported in part by the U. S. Atomic Energy Commission.

**K11. Transmutation of Elementary Particles.** Gertrude Tiring Schwarzmann.—If we assume that there exists a maximum value $v^*=0.993C$ of the velocity of elementary particles and express by $\delta \cdot b \cdot v^2/7.3$ the frequencies of electrons moving at velocity $v$: electrons *in fact and name* strictly obey the rule that $\delta$ is unity for velocities smaller than $v$ and exceeds unity exclusively for maximum velocity. This rule is strictly obeyed by satellites on formation of, in stable, on beta decay of antineutrons and neutrons. When powerful projectiles hit antineutrons and neutrons, the emerging satellite describes at $\delta$ 959 as $\tau$ meson the first; at $\delta$ 274 as pion(s) the second; at $\delta$ 205.5 as muon(s) the third, as electrons(s) in fact and name, the fourth section(s) of its track. All transmutations occur in flight, all mesons decreasing their velocities not below unity before transmutation. Vector sum total of the momenta in the laboratory system of all quatiary electrons, tertiary and secondary mesons, and primary meson is the initial momentum; sum total of their kinetic energies in the laboratory system the initial kinetic energy of the satellite on ejection.

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## Tuesday Morning at 9:30

## Sheraton Hall

(S. E. Forbush presiding)

### *Cosmic Rays*

**L1. Daily Variation of the Nucleonic Component of Cosmic Rays.** J. Katzman and D. Venkatesan, *National Research Council, Canada.*—A time series study of the nucleonic component of cosmic rays of 17 stations from 88°N to 73°S geomagnetic was made. A worldwide barometer coefficient of $-72\%$/mb was obtained from the second harmonic components of both pressure and nucleonic intensity with a high negative correlation between the respective phases of the hours of maximum. The diurnal component was corrected for pressure with this coefficient and the remaining intensity was obtained free of meteorological effects, if it is accepted that the nucleonic component is pressure sensitive only. The remaining diurnal intensity was found to be of the order of 0.3% and the hour of maximum was at $14\pm2$ hr for the period August, 1957 to October, 1958. There exist considerable differences in amplitude as well as the times of maxima of the diurnal component amongst various stations at approximately the same geomagnetic latitude. Since studies of individual stations for short periods (15 months) show considerable variability it is concluded that a study of as many and for as long a period as possible is necessary before any definite statement can be made of the anisotropy of cosmic rays.

**L2. Relationship between Ground Level Neutrons and High-Altitude Heavy Primary Cosmic Rays.*** O. B. Young and T. P. Wang, *Southern Illinois University.*—This is a preliminary and inclusive, but indicative, report. A comparison was made of the variation of heavy primary cosmic-ray flux at the top of the atmosphere, and of the neutron variation at the ground at the same time. Balloon flights were made at times of different solar activities for the same latitudes. The heavy nuclei were restricted to $Z$ of 10 or greater. Two flights at Prince Albert, Canada, August, 1957 yielded about 2000 tracks on $G.5$ emulsions. The results indicate that the heavy primaries do not vary proportionately with the neutrons, as do protons and alphas. Instead the heavies vary about one-fourth as much. The investigation is being extended to other latitudes.

* Supported in part by the Office of Ordnance Research and the International Geophysical Year program. Appreciation is expressed to John A. Simpson and Peter Meyer at the University of Chicago for their assistance.

**L3. Cosmic-Ray Neutrons at High Balloon Altitudes.** R. C. Haymes and S. A. Korff, *New York University.**—In order to extend measurements of cosmic-ray neutrons to top balloon altitudes a flight was conducted on August 24, 1959.

in which our system of identical counters filled with enriched and depleted $B^{10}F_3$ was used. An altitude of 122 000 ft was attained, corresponding to 4-mb pressure, which is considerably higher than previous measurements. From a maximum of about 300 corrected neutrons counts per minute at 55 000 ft, the counting rate dropped to much lower values at the top of the flight. The background due to highly ionizing particles also decreased markedly. The experiment determines the density of neutrons in the $1/v$ region. At the high-altitudes the counter measures both neutrons locally produced and neutrons diffusing upward from the region of maximum production. The bearing upon albedo flux and spectrum will be discussed.

* Supported in part by the joint Office of Naval Research and U. S. Atomic Energy Commission program.

**L4. Solar Cosmic Rays over the North Magnetic Pole.*** K. A. ANDERSON† AND D. C. ENEMARK, *State University of Iowa.*—Following a large solar flare on July 16, 1958, fluxes of protons in the energy region 85 to 300 Mev in a steep spectral distribution were observed by means of high-altitude balloons over Resolute Bay, Canada. The flare particle intensity decreased rapidly and quite steadily over the period of several days but on the occasion of the last flight launched on July 27 a small flux remained above the high-energy cosmic-ray level. At that time the active region in which the flare occurred was nearly opposite central meridian. The time dependence of the particle intensity followed quite well a $t^{-3}$ law where $t$ equaled zero about 16 hr after the flare. Because these low-energy particles have only a short lifetime in the solar system and since their energy changes unappreciably during this time, it is unlikely that the high-energy cosmic radiation can be local in the sense of being confined to the inner solar system. This intense flare radiation was found to contain very little fast helium so that it is probably not suitable as a raw material for the energetic galactic radiation.

* Supported by the National Science Foundation.
† Guggenheim Fellow, now at Royal Institute of Technology, Stockholm.

**L5. Solar Protons and α Particles.*** PHYLLIS S. FREIER, *University of Minnesota.*—The flux and energy spectrum of protons and $\alpha$ particles received at the earth after the class 3+ flare of 0210 July 10, 1959 has been studied in nuclear emulsions during two balloon flights at Churchill, Canada, and four at Minneapolis, Minnesota. These flights cover the time interval from 9 to 69 hr after the commencement of the flare. The time dependence of the protons and alphas will be given.

* This work supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**L6. Intensity of Heavy Nuclei ($Z \geq 3$) of Cosmic Rays Following a Solar Flare.*** SUKUMAR BISWAS,† *University of Minnesota.*—During a period of 66 hr following a 3+ solar flare on July 10, 1959, emulsion stacks were exposed in six balloon flights—four from Minneapolis and two from Churchill, Canada. The vertical flux of heavy nuclei of $Z>3$ at an atmospheric depth of about 10 g/cm² has been obtained in Minneapolis flights. During a period of 7 to 19 hr after the flare, the flux of heavy nuclei ($Z \geq 3$) at 11 g/cm² of air was $15.9 \pm 2.4$ particles/m² sec sr and during 27 to 41 hr, the value was $14.2 \pm 2.3$ particles/m² sec sr. These intensities will be compared with those obtained during other flights. The implication of the results will be discussed in relation to the solar protons and $\alpha$ particles observed during this period.

* This work was supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave from Tata Institute of Fundamental Research, Bombay.

**L7. Heavy Component of the Primary Cosmic Radiation during Solar Maximum.*** C. E. FICHTEL,† *Washington University.*—The heavy component of the primary cosmic radiation was studied at geomagnetic latitude 55°N at a time of solar maximum. The total flux was found to be down by a factor of about two, compared to the results obtained during solar minimum, but the charge spectrum was found to be the same, to within experimental errors. The extrapolated fluxes at the top of the atmosphere were found to be: $3.08 \pm 0.64$ particles/(m² sr sec) for $3 \leq z \leq 5$, $8.26 \pm 0.82$ particles/(m² sr sec) for $6 \leq z \leq 9$, and $2.96 \pm 49$ particles/(m² sr sec) for $10 \leq z$. When this work is combined with that of other experimentalists at different latitudes and compared to the solar minimum data, the change in the integral energy sepctrum is found to be in fair agreement with the predictions of an electric deceleration modulating mechanism.

* Supported by the U. S. Air Force Office of Scientific Research and the National Science Foundation.
† Present address: Goddard Space Flight Center, Washington, D. C.

**L8. Heavy Nuclei in the Primary Cosmic Radiation at Prince Albert, Canada.*** M. KOSHIBA, H. AIZU, Y. FUJIMOTO, S. HASEGAWA, I. MITO, J. NISHIMURA, AND K. YOKOI, *University of Tokyo,* AND MARCEL SCHEIN, *University of Chicago.*—Our previous investigation[1] of the low-energy carbon, nitrogen, and oxygen nuclei in the primary cosmic radiation has been extended to cover the other nuclear species: alpha particles, lithium, beryllium, and boron, and the elements of $Z \geq 9$. Only the stopping tracks have been used to obtain the data on the elements of $Z \geq 9$. For the results of lithium, beryllium, and boron nuclei, all the tracks that stopped, traversed, and interacted have been analyzed, and special caution has been given to the separation of relativistic carbons from slow borons of energy around 400 Mev per nucleon. The energy spectrum of alpha particles has been obtained by measuring their ionizations at both entrance and exit of the stack. All the energy spectra of these elements, except for a possible slight deviation of lithium, beryllium, and boron, showed a similar shape to that observed in 1. for carbon, nitrogen, and oxygen. The element abundances are essentially the same as in the high energy region of $\gtrsim 1$ Bev per nucleon.

* This work has been supported in part by the U. S. National Committee of IGY, the National Science Foundation, and the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] H. Aizu, Y. Fujimoto, S. Hasegawa, M. Koshiba, I. Mito, J. Nishimura, K. Yokoi, and M. Schein, Phys. Rev. 116, 436 (1959).

**L9. New Method to Determine the Charge of Cosmic-Ray Heavy Nuclei with Nuclear Emulsions.*** GABRIEL ALVIAL,† *University of Chicago.*—The electrical charge of relativistic heavy nuclei of cosmic radiation is determined by measuring the density of the very little $\delta$ rays. The method is described. A previously reported method and results[1] are improved by measuring tracks corresponding to well-known calibrated cases of fragmentations. A complete accordance between the density of very little $\delta$ rays and the distribution function of the free path to produce these $\delta$ rays is found. The measurements near the iron charge are discussed. Also some examples of measurements performed at the end of range on protons, $\alpha$ particles, lithium, beryllium, and boron nuclei are presented.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the National Science Foundation.
† As Fellow of the John Simon Guggenheim Memorial Foundation and on leave from the University of Chile.
[1] G. Alvial *et al.*, Nuovo cimento (to be published).

**L10. Charge Distribution of Cosmic-Ray Primaries.*** C. A. RANDALL, JR., *Ohio University.*—We have measured the charges of cosmic-ray particles having $Z \geq 3$ which were recorded by a cooperative[1] stack of 400 $\mu$ *G*-5 pellicles at 116 000 ft and 100 000 ft near the magnetic equator. For $2 < Z < 8$ the charge of each particle was determined un-

ambiguously from the slope of the gap distribution as previously reported.[3] For $Z>8$ the δ-ray density was used to determine the charge. The histogram is in qualitative agreement with that reported by the Minnesota group.[4] The development of a microdensitometer method of measuring the charge of particles of $Z>8$ is in progress. Preliminary results indicate that it is significantly mroe objective than δ-ray counting. The method will be discussed.

* Supported by the National Science Foundation and The Ohio University Fund Inc.
[1] University of Buffalo, University of Chicago, University of Missouri, Ohio University, and Reed College.
[3] R. A. Mollison, L. J. Gallaher, and C. A. Randall, Jr., Bull. Am. Phys. Soc. Ser. II, 4, 6 (1959).
[4] P. S. Freier, E. P. Ney, and C. J. Waddington, Phys. Rev. 113, 921 (1959).

**L11. Nuclear Interactions of Protons at Energies $>10^{12}$ ev in Nuclear Emulsion.*** E. LOHRMANN, A. G. BARKOW,† B. CHAMANY, D. M. HASKIN, P. L. JAIN,‡ M. W. TEUCHER, AND MARCEL SCHEIN, *University of Chicago.*—A stack of nuclear emulsion consisting of 200 pellicles 60 cm×30 cm, 600-$\mu$ thick, was exposed for 13 hr at 116 000 ft over Texas. Eighty-four high-energy nuclear interactions (jets) were located by scanning for electromagnetic cascades which were traced back to their origin. The angular distribution of the shower particles was measured for 57 events having a dip angle $\leq 17°$. These distributions will be discussed with respect to various models of multiple meson production.

* Supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and the National Science Foundation.
† On leave from Marquette University, Milwaukee, Wisconsin.
‡ On leave from the University of Buffalo, Buffalo, New York.

**L12. Neutron Production in U, Pb, W, and Sn by Cosmic-Ray Protons of Selected Energies between 250 and 900 Mev.** M. BERCOVITCH, H. CARMICHAEL, G. C. HANNA, AND E. P. HINKS, *Chalk River Laboratories.*—Low-energy neutron production in U, Pb, W, and Sn by cosmic-ray protons of six selected energies between 250 and 900 Mev was measured. Protons were selected and their energy measured by a vertical counter telescope containing liquid nitrogen, water, and Plexiglas Čerenkov detectors. The protons interacted in 22- and 44-g cm$^{-2}$ thick targets, and the neutrons produced were detected in a 4-ft cubic paraffin moderator, $B^{10}F_3$ counter assembly below the telescope. The data were obtained principally at 3160-m altitude; runs at 150 m were made to check the mountain data for muon contamination of the selected particles. The proton-gated neutron rates were converted to mean neutron multiplicities per interaction using (a) the neutron efficiency measured with $Pu^{240}$ spontaneous fission and Ra-α-Be neutron sources, (b) the interaction cross sections of Chen, Leavitt, and Shapiro. The multiplicities range from 5.8±1.0 for 300-Mev protons on 33-g cm$^{-2}$ thick Sn, to 26.7±4.2 for 820-Mev protons on 44-g cm$^{-2}$ thick U. The multiplicities predicted from the Monte Carlo nucleon cascade calculation of Metropolis *et al.* and the Monte Carlo evaporation calculation of Dostrovsky *et al.* agree with the measurements when secondary neutron production in the thick targets is considered.

**L13. Interplanetary Gas Cloud Modulation of Cosmic Rays.*** H. LASTER, A. M. LENCHEK, AND S. F. SINGER, *University of Maryland.*—As suggested by Morrison, solar activity is assumed to be associated with the ejection of a cloud of magnetically turbulent gas. We note however that in passing from the sun to the earth, this cloud *expands* significantly. Cosmic rays random-walk in the turbulent magnetic field of the cloud, making predominantly "overtaking" collisions with the magnetic inhomogeneities, which are receding from one another. This effect, together with the betatron deceleration in the weakening mean field, dominates over the statistical Fermi acceleration, and results in "diffusive deceleration" of the particles.[1] Application of the extended Liouville theorem then shows that the intensity within the cloud is depressed; intensity as a function of position is obtained by an age-diffusion calculation. When the cloud envelops the earth, a Forbush decrease results. Its calculated dependence on time and on energy is in good agreement with observations.[2]

* Supported by the Air Force Office of Scientific Research.
[1] S. F. Singer, Nuovo cimento 8, (Suppl. II), 334 (1958).
[2] F. B. McDonald and W. R. Webber, Phys. Rev. 115, 194 (1959).

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## TUESDAY AFTERNOON AT 2:00

Sheraton Hall

(R. JASTROW presiding)

### *Space Physics*

**M1. Interaction of Low-Energy Solar Cosmic Rays with the Disturbed Geomagnetic Field of the Earth.*** J. R. WINCKLER, *University of Minnesota.*—During geomagnetic storms a number of well-defined cases exist in which solar cosmic rays gain entrance to the earth's surface at latitudes considerably below those allowed by Strörmer theory, although these particles have a low-energy density and may be considered as single particles. The perturbations of the geomagnetic field are presumed caused by the high energy density solar gas plasma. Rothwell[1] and Obayashi and Hakura[2] have developed theories to relate the minimum latitude of entrace with the maximum penetration of the solar plasma into the geomagnetic field. The comparison of these theories with balloon observations of solar cosmic rays at Minneapolis, which is normally a forbidden latitude for these particles, will be discussed. The geomagnetic storms all involved strong Forbush decreases of galactic cosmic rays. Therefore a solar-generated magnetic field may be assumed to exist near the earth. This external field may also provide a mechanism for the appearance of the low-energy cosmic rays at normally forbidden latitudes.

* This work supported by a joint program of the Office of Naval Research and the U.S. Atomic Energy Commission and by the National Science Foundation.
[1] P. Rothwell, J. Geophys. Research 64, 2026 (1959).
[2] T. Obayashi and Y. Hakura, "Report of ionosphere and space research in Japan," Vol. XIII, No. 4 (1959).

**M2. Scintillation Counter Observations of Auroral γ Rays.*** P. D. BHAVSAR, *University of Minnesota* (introduced by J. R. Winckler, University of Minnesota).—Auroral x rays were observed at 10 g/cm$^2$ atmospheric depth over Minneapolis on May 12, 1959, with a balloon-borne NaI scintillation spectrometer in the energy range 22 kev to 263 kev. This event accompanied the low-energy solar cosmic rays which also produced some photon effects in the atmosphere. Differential

energy spectrum of the x rays was obtained after correcting for these effects. The time variation of the energy spectrum has also been studied. The peak in the auroral x-ray intensity was found to be associated with the passage of the aurora at the zenith. An attempt has also been made to obtain the x-ray energy spectrum at production and the electron energy spectrum responsible for it. It is believed that the auroral x rays are due to the discharge of electrons from the outer Van Allen belt. Further experiments are in progress for the study of continuous leakage from the Van Allen belt.

* This work was supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by the National Science Foundation.

**M3. Time Variations in the Earth's Trapped Radiation as Measured by Explorer VI Satellite.*** R. L. ARNOLDY AND J. R. WINCKLER, *University of Minnesota.*—Instrumentation on Explorer VI detected three definite maxima in the earth's trapped radiation; the Van Allen inner region, and two others at 17 000 and 21 000 km measured near the equator. The two inner regions are very stable and have ionizing powers 5 to 6 times that for minimum ionizing particles as compared with the fluctuating soft outer region with radiation 15 times minimum ionizing. The strong geomagnetic storm commencing at 0404 GMT, August 16, 1959, diminished the intensity of the soft region to one-third of its prestorm value and hardened the radiation, as measured on August 17, 0500 GMT. The *D*st curve for the storm as plotted by Chapman and Akasofu for equatorial stations shows 90% recovery from the main phase by August 18, 1100 GMT, when the intensity of the soft maximum had recovered to prestorm levels. The soft radiation region continued to increase in intensity to five times this level by August 20, giving a peak dosage of 50 r/hr of soft x rays measured behind a minimum of 0.5 grams of aluminum. Coincident with this sustained high intensity which lasted for a week before decaying to prestorm levels was a long-lasting solar radio noise storm.

* This research was supported by the NASA.

**M4. Characteristics of the Earth's Trapped Radiation as Measured by Explorer VI Satellite.*** R. A. HOFFMAN AND J. R. WINCKLER, *University of Minnesota.*—From data received from an integrating ionization chamber and Geiger counter aboard Explorer VI satellite, the characteristics of the earth's trapped radiation during relatively stable periods are determined. Particle flux and ionizing power contours are plotted for August 7–14, 1959, and flux contours for the periods August 25–30 and September 7–10. The pitch angle distributions at the equator are obtained during these times from the measured counting rates along a line of force from the equator to the earth's surface. Appreciable changes in the distributions with time are observed. It is found that the mean ionization per particle compares with that obtained from the spectra of Vernov[1] and Walt *et al.*[2] From a plot of particle flux vs altitude it is shown that atmospheric heating cannot be an important mechanism for "dumping" the outer region. From the contours, pitch angle distributions, and time variations of intensity, requirements for injection and dumping mechanisms are established.

* This research was supported by the NASA.
[1] Vernov *et al.*, Doklady Akad. Nauk S. S. S. R. 125, 304 (1959).
[2] Walt *et al.*, Preprint, Lockheed Missiles and Space Division, Palo Alto, California, 1959.

**M5. Star Production by Trapped Protons in the Inner Radiation Belt.** HERMAN YAGODA, *Air Force Cambridge Research Center.*—A 4-lb block of Ilford *G*5 emulsion recovered from an Atlas rocket which reached an elevation of 1176 km shows a rate of star production ($N_A \geq 3$ prongs) of 293 000 $\pm$13 000 cc$^{-1}$ d$^{-1}$ roughly 700-fold greater than that anticipated from the equatorial cosmic-ray exposure. The nuclear evaporations are of small multiplicity 98.5% of the spectrum showing $N_A < 8$. In Viking rocket flights with apogees below the Van Allen belts small stars with $N_A < 8$ constituted 63% of the spectrum. The large star population in the Atlas emulsions is attributed to interactions of trapped protons of kinetic energy $\geq$150 Mev. Use of a star production mean free path of 49.7 cm of emulsion provides an estimate of the omnidirectional flux of trapped protons of $E \geq 150$ Mev of $170_{-10}^{+30}$ sec$^{-1}$ cm$^{-2}$ assuming a 400-sec exposure in the radiation belt and that the trapped protons entered the emulsions over $4\pi$ sr.

**M6. Geomagnetic Anomalies and the Van Allen Radiation Belts.** DUANE C. JENSEN, J. A. WELCH, JR., AND W. A. WHITAKER, *Air Force Special Weapons Center.*—This analysis is based on a new multipole expansion ($n \leq 25$, $m \leq 18$) of the geomagnetic field based on surface data, the adiabatic invariant formulation for charged particle motion, and multiple scattering as the loss mechanism. The results describe the altitude of the lower edge of the Van Allen belts as a function of geographic position and explain the sharpness of this lower edge. A comparison of the predicted shape of the Argus shell with observations will be made.

**M7. Densities of Electrons from Neutron Decay Trapped by the Geomagnetic Field.*** J. KILLEEN AND W. N. HESS, *Lawrence Radiation Laboratory, Livermore.*—The cosmic-ray neutron energy spectrum has been measured experimentally.[1] From this spectrum, calculations have been made of the neutrons leaking out of the atmosphere of the earth which give the strength of the neutron decay source at all points in space.[2] From the given electron source distribution a source density along field lines is calculated. Using a code previously discussed, the density of mirror points along field lines resulting from the decay source is then calculated. From this injection mirror point density an equilibrium mirror point density is calculated by including losses due to atmospheric scattering.[3] From this density distribution the trapped particle density along field lines is calculated. The results are given as a function of field line and geomagnetic colatitude in particles/cm$^3$.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] W. N. Hess, H. W. Patterson, R. Wallace, and E. L. Chupp, Bull. Am. Phys. Soc. Ser. II, 4, 223 (1959).
[2] W. N. Hess, Bull. Am. Phys. Soc. Ser. II, 4, 365 (1959).
[3] N. Christofilos, "Trapping and lifetime of charged particles in the geomagnetic field," UCRL-5407 (1958); J. A. Welch, "Theory of geomagnetically trapped electrons from an artificial source," talk given at Natl. Acad. Sci., April, 1959.

**M8. Particle Fluxes in the Inner Radiation Belt.*** STANLEY C. FREDEN AND R. STEPHEN WHITE, *Lawrence Radiation Laboratory, Livermore.*—By using the albedo neutron decay source, the energy spectrum of trapped protons in the inner belt has been calculated form 10–700 Mev. This calculation differs from those of Singer and Hess in that a nuclear interaction term, in addition to the energy loss term, has been used in the continuity equation for the steady-state condition. The spectrum agrees well with the published data. This agreement is strong evidence for the albedo neutron decay source. It also indicates that nonadiabatic effects are small for the particles measured here. A second small stack of nuclear emulsions was flown at the lower edge of the inner radiation belt eleven days after the large solar flare of May 10. The ratio of the proton flux measured on the second flight to that of the first one is 0.8$\pm$0.1. This indicates that the solar flare had little or no effect on the proton content of the inner belt. A flux of 2$\pm$1 tritons/cm$^2$/sec between 126 and 200 Mev

was observed. It is attributed to collisions of trapped protons with air nuclei. No other nuclei heavier than protons were seen.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**M9. Scintillation Counter Observations from Explorer IV on Trapped Charged Particles between the Inner and Outer Van Allen Radiation Zones.** P. ROTHWELL AND C. E. MCILWAIN, *State University of Iowa.*—The plastic scintillator carrier in Explorer IV showed a peak in counting rate along the satellite orbit at ~45° magnetic latitude during August, 1958 (i.e., in the "slot" between the inner and outer Van Allen radiation belts); the Geiger counters in the satellite did not record this peak. Peak intensity varied considerably from day to day and the geographic location of the peak maximum shifted a few degrees towards the equator on days when high intensities were recorded. The particles responsible for the 'peak in the slot' are of higher energy, but lower intensity than the particles found at higher latitudes, at the fringe of the outer radiation belt. Observations from Explorer VI by the Minnesota and Chicago groups during August, 1959, on the distribution of charged particles in space, showed an intensity peak near the equatorial plane at ~2.5 earth radii (between the inner and outer Van Allen radiation belts). The scintillation counter in Explorer IV probably registered particles at the fringe of this intermediate zone.

**M10. Effect of Geomagnetic Storms on the Van Allen Radiation.** R. KARFLUS* AND A. J. DESSLER, *Lockheed Missiles and Space Division.*—Observations[1] made with the Explorer VI satellite system have shown that the radiation intensity in the outer zone of the Van Allen radiation belt decreases during the active phase of a geomagnetic storm. The radiation intensity increases markedly immediately after this active phase. It will be shown that these changes can be accounted for by geomagnetic storm effects. The origin of the electrons which constitute the outer zone of the radiation belt is attributed to neutron decay. It will be argued that the observed features of the outer zone cannot be explained by the solar injection hypothesis.

* Present address: University of California, Berkeley.
[1] C. Y. Fan, P. Meyer, and J. A. Simpson, presented at The First International Space Science Symposium, Nice, France, January 11–15, 1960 (unpublished); R. Arnoldy, R. Hoffman, and J. R. Winkler, *ibid.*; A. Rosen, T. A. Farley, and C. P. Sonett, *ibid.*

**M11. Experiment to Determine Accurately the Polarization and Intensity of the Light from the Solar Corona.*** E. P. NEY, W. F. HUCH, P. J. KELLOGG, AND R. W. MAAS, *University of Minnesota.*—Kellogg and Ney presented a theory that the solar corona may consist of charged particles trapped on a solar magnetic field. In order to test the possibility that synchrotron radiation in the visible might be detected from the solar corona, equipment has been constructed which measures the absolute intensity of polarized and unpolarized light from the corona, at wavelengths of 4500 A and 8500 A. It consists essentially of television cameras attached to telescopes and using photomultipliers as detectors. The accuracy of the equipment is such that the absolute intensities of polarized and unpolarized light from the corona may be measured to 5%, and the direction of the polarization angle may be measured to an accuracy of ±0.8 degree. This equipment was successfully used on two sites in the Sahara Desert to measure the polarization of the corona during the eclipse of October 2, 1959. At each of these two sites, successful data were obtained for five complete scans of the corona in each color of light.

* This work was supported jointly by the Office of Naval Research, the National Science Foundation, and the NASA.

**M12. Results of the Measurement of the Polarization of Coronal Light on October 2, 1959.*** P. J. KELLOGG, E. P. NEY, AND W. F. HUCH, *University of Minnesota.*—Three complete scans of the sun's corona at wavelengths of 4500 A and 8500 A have been analyzed to determine the intensities of polarized and unpolarized light during the eclipse of October 2, 1959. The measurement of polarized and unpolarized light allows one to separate the coronal light into *F* corona and *K* corona, the *F* corona coming from dust scattering along the line of sight, and the *K* corona coming from the true electron density in the corona itself. The results of this experiment will be discussed in terms of (1) intensity of the corona at sunspot maximum; (2) wavelength dependence of the coronal intensity; (3) time variations in the coronal light; and (4) possible deviations from radial polarization and their significance in terms of synchrotron radiation from a trapped corona.

* This work was supported jointly by the Office of Naval Research, the National Science Foundation, and the NASA.

**M13. Solar Radio Emission during August 18–September 4, 1959.** WILLIAM C. ERICKSON, *Convair Scientific Research Laboratory.*—Intense solar radio emission at 11.4-m wavelength was observed during August 18–September 4, 1959. This period of solar radio activity is of interest since it is apparently correlated with an increase in the intensity of the outer Van Allen belt found through Explorer VI measurements. High angular resolution studies of the radio emission were performed with the two-mile array at the Clark Lake radio astronomy station. It is found that the radio emission did not occur in a single region, correlated with a single photospheric feature, but rather, the emission occurred in several complex regions. These emission regions apparently existed in the corona above several of the plage regions observed near the photosphere.

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## TUESDAY AFTERNOON AT 2:00

Adams-Hamilton Room

(W. M. McDONALD presiding)

### *Positrons; General Nuclear Physics*

**MA1. Direct Pair Production by 800-Mev Electrons.*** B. M. CHASAN, R. M. SCHECTMAN, AND D. H. WHITE, *Cornell University.*—The Cornell 24-in. diffusion cloud chamber, filled with argon at one atmosphere pressure, and operating in a magnetic field of 6000 gauss, is currently being employed to measure the cross section for the direct production of electron-positron pairs by 800-Mev electrons. The electrons are produced in a radiator by the bremsstrahlung beam from the Cornell synchrotron, and are momentum-selected and steered into the cloud chamber by two bending magnets. An average of about 20 electron tracks is obtained in each picture. Preliminary results concerning the total cross section

and the energy partition among the secondary particles will be presented.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**MA2. Positron Annihilation in LiH.** R. H. MARCH AND A. T. STEWART, *Dalhousie University.*—We have measured the angular correlation of photon pairs from positrons annihilating in LiH. The data yield the momentum distribution of the center of mass of the annihilating pairs. Assuming that the positrons annihilate with one type of electrons only—the $1s$ electrons of the hydride ion—and postulating the form $\exp(-\alpha r^2)$ for the electron-positron wave function product, we obtain a good fit to the observed momentum distribution for $\alpha=0.70/A^2$. For this value of $\alpha$, the spacial distribution of the square of the wave function product is more extended than the electron density distribution obtained from x-ray measurements[1] by a factor of about 1.7. This is in sharp contrast with the results for alkali halides[2] which showed the two distributions to be about the same size. It appears that the negative ion electrons are much more perturbed by the presence of the positron in LiH than in the alkali halides. To interpret these data in terms of single-particle wave functions, a self-consistent field calculation for both electrons and positron will be necessary. This experiment provides a simple criterion (the wave function product) for the direct testing of such a calculation.

[1] W. Cochrane, Revs. Modern Phys. **30**, 47 (1958).
[2] A. T. Stewart and N. K. Pope, Phys. Rev. (to be published).

**MA3. Annihilation-in-Flight of 780-Mev Positrons.*** E. MALAMUD AND R. WEILL,† *Cornell University.*—The interactions of high-energy positrons and electrons with electrons are being studied in a 6-in. diameter propane bubble chamber. Positrons are created by passing the bremsstrahlung beam from the Cornell synchrotron through a copper target placed in an analyzing magnet. A second magnet steers the positrons into the bubble chamber which itself is in a magnetic field of about 7500 gauss. Stereoscopic photographs are taken through a hole in the magnet pole. In the photographs scanned to date an annihilation event is found in approximately every 40 pictures with an average of 4 tracks per picture. When the currents in the analyzing and steering magnets are reversed an electron beam enters the chamber. This provides a useful background measurement.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from Laboratoire Recherches Nucléaire, E.P.U.L., Lausanne, Switzerland.

**MA4. Bremsstrahlung Spectrum of 780-Mev Positrons and Electrons.*** R. WEILL† AND E. MALAMUD, *Cornell University.*—The experimental equipment described in the previous abstract is being used to measure the shape of the bremsstrahlung spectrum near the high photon energy end. The pictures are scanned for events in which a primary particle enters the chamber and then undergoes an abrupt change of curvature. For events corresponding to emission of a very high energy photon, range measurements are made on the residual electron track. The number of events is plotted versus the fraction, $v$, of primary energy given to the photon. Residual electron energies down to 1 Mev can be determined; thus the method makes it possible to measure events corresponding to $v$ up to about 0.998.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from Laboratoire Recherches Nucléaire, E.P.U.L., Lausanne, Switzerland.

**MA5. Positron Annihilation in Sodium Chloride.** N. K. POPE, *Chalk River Laboratories.*—The cellular method has been used to calculate the lowest energy wave function for a positron in a sodium chloride lattice. In a cell associated with a given ion of the lattice, the potential energy of the positron was assumed to be that due to the corresponding free ion plus a Madelung term. A four parameter approximate solution of the resulting positron Hamiltonian was expanded in lattice harmonics about an origin on a chloride ion. Using, for the electrons, tight-binding lattice wave functions (constructed from free-ion electron wave functions) the momentum distribution of the $\gamma$ rays from 2-photon annihilation has been calculated. For annihilations with $3s$ and $3p$ electrons, the contributions to the momentum distribution of the positron wave-function lattice harmonics of order four and six is negligible compared to that of the zero-order harmonic. The calculated momentum distribution can be normalized so that it agrees with the measured distribution[1] from 0.0036 to 0.012 Mc. Deviations at low momenta are expected, owing to the approximate nature of the electron wave functions and to the neglect of electron positron correlations.

[1] A. T. Stewart and N. K. Pope (to be published).

**MA6. Positron Annihilation in Condensed Hydrogen.** D. C. LIU AND W. K. ROBERTS, *NASA Lewis Research Center.*—The long mean life of positronium observed[1] in both liquid and gaseous helium below 9°K suggests that the physical state of the helium is not important to the pick-off mechanism. This is a surprising result for there are several examples where there is a marked change in the pick-off rate accompanying a change in phase. The aim of the present investigation was to observe the pick-off rate in hydrogen for the gaseous, liquid, and solid phases. The method was to observe the mean life of annihilation radiation timed from the 1.28-Mev gamma ray of $Na^{22}$. NE102 scintillation counters with 6810 A photomultipliers were used as detectors and a time-to-pulse height converter displayed the time delays in a 200-channel analyzer. The prompt curve of this system had a half-width of $\sim$3 $m\mu$sec. A preliminary experiment has indicated that the long life time, $\tau_2$, is doubled while its intensity, $I_2$, stays the same in a solid to liquid phase change.

[1] T. B. Daniel and R. Stump, Phys. Rev. 115, 1599 (1959).

**MA7.** (Abstract withdrawn).

**MA8. Nuclear Resonance Absorption in $Re^{187}$.** R. L. MÖSSBAUER* AND W. WIEDMANN, *Technische Hochschule München* (introduced by F. Boehm).—Nuclear resonant absorption of gamma rays has been observed at a temperature of 20°K in $Re^{187}$ using a recoil-free gamma ray emitted by nuclei strongly bound in a crystal lattice. In this method[1] the gamma quanta do not suffer any observable energy loss by recoil in the emission and absorption processes, the recoil momentum in both cases being taken up by the whole crystal-

lite and not by the individual nucleus. For this reason the resonance condition is ideally fulfilled at zero velocity between source and absorber. By using a relative velocity of the order of 10 cm/sec, the line emitted in the 134-kev transition in $Re^{187}$ has been shifted away from the absorption line of the same transition, resulting in the destruction of the resonance phenomena. Analysis of the variation in transmission as a function of the Doppler shift of the emitted $\gamma$ ray yields a value of $\tau=(1.5\pm0.2)\ 10^{-11}$ sec for the lifetime of the 134-kev excited state in $Re^{187}$.

* Now at California Institute of Technology, Pasadena.
[1] R. L. Mössbauer, Z. Naturforsch. 14a, 211 (1959).

**MA9. Range-Energy Measurements for 2- to 5-Mev Protons in Ni and Ag.*** B. J. FARMER, *Vought Research Center*, AND H. BICHSEL, *University of Southern California*.—Few precise range-energy measurements for protons have been made between 2 and 5 Mev. The present report, an extension of previous work,[1] is intended to add to this data. The proton energies are determined with respect to various $(p,n)$ thresholds using The Rice Institute's Van de Graaff accelerator. The range measurements are made with a triple coincidence proportional counter.[1]

TABLE I.

| Nickel | | Silver | |
|---|---|---|---|
| $E_p$ (Mev) | $R_{exp}$(mg/cm²) | $E_p$ (Mev) | $R_{exp}$(mg/cm²) |
| 1.954±0.008 | 15.06±0.03 | 1.893±0.007 | 18.77±0.03 |
| 2.646±0.008 | 23.95±0.03 | 2.408±0.008 | 27.27±0.03 |
| 3.342±0.008 | 34.40±0.03 | 3.222±0.010 | 42.84±0.04 |
| 3.993±0.009 | 45.76±0.04 | 3.745±0.011 | 54.05±0.05 |
| 4.467±0.011 | 54.80±0.04 | 4.374±0.012 | 69.06±0.05 |
| 5.098±0.012 | 67.85±0.05 | 4.765±0.012 | 79.38±0.05 |
| | | 5.242±0.014 | 91.81±0.05 |

* Experimental work performed at The Rice Institute supported in part by the U. S. Atomic Energy Commission.
[1] H. Bichsel and B. J. Farmer, Bull. Am. Phys. Soc. Ser. II, 2, 15 (1957).

**MA10. Range-Energy Relations for Protons in Various Substances.*** R. M. STERNHEIMER, *Brookhaven National Laboratory*.—An expression has been obtained for the range-energy relation $R(T_p)$ for protons ($T_p$ = proton kinetic energy) as a function of the mean excitation potential $I$ which enters into the Bethe-Bloch formula for the ionization loss $dE/dx$. The expression for $R(T_p)$ is obtained by an interpolation of the previously calculated range-energy relations[1] for Be, Al, Cu, and Pb. The result for $R(T_p)$ is accurate to within 1% for values of $I$ between 60 and 1100 ev. The expression for $R(T_p)$ can be used to calculate the range-energy relation for any substance, provided an appropriate value of $I$ is assumed. Conversely, from a range measurement at a given $T_p$, one can deduce the value of $I$ for the substance. Values have also been obtained for the quantity $q\equiv(I/R)(dR/dI)$, which gives the fractional change of $R$ for a small variation of $I$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. M. Sternheimer, Phys. Rev. 115, 137 (1959).

**MA11. Comparison of Polonium-Alpha Energy with the $Li^7(p,n)Be^7$ Threshold.*** C. P. BROWNE, J. A. GALEY, J. R. ERSKINE, AND K. L. WARSH, *University of Notre Dame*.—Recent absolute measurements[1] of the $Po^{210}$ alpha-particle energy disagree with the older value used as the standard for many nuclear $Q$-value measurements. A new comparison with the Li threshold was made using the Notre Dame electrostatic accelerator and broad-range spectrograph. The threshold was run, and then protons or deuterons were scattered from appropriate targets so that the scattered group was recorded on the spectrograph plate near the $\alpha$ group from a source placed at the targer position. First, the spectrograph and, second, the beam analyzer were used to compare particle momenta. Thirdly, with both fields constant after the threshold was run with the molecular beam, deutrons were scattered, giving particles of the same $B\rho$ as the alphas. Fourthly, the $Mg^{24}(d,d')Mg^{24*}$ reaction was used to measure the excitation of the first state in terms of Po $\alpha$ energy and the result compared to the known value based on the Li threshold. The four measurements agree and give a preliminary value of 5.309 ±0.005 Mev for Po alpha based on 1.8811 Mev for the $Li^7$ threshold. This agrees with the latest measurement.[1]

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] See F. A. White, F. M. Rourke, J. C. Sheffield, R. P. Schuman, and J. R. Huizenga, Phys. Rev. 109, 437 (1958), for latest measurement and for summary.

## *Invited Papers*

**MA12. A Detector for the Accurate Measurement of Particle Velocity and Direction over a Wide Angular Range.** ARTHUR ROBERTS, *University of Rochester*. (30 min.)

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TUESDAY AFTERNOON AT 2:00

National Bureau of Standards, East Building

(H. P. R. FREDERIKSE presiding)

## *Semiconductors*

**N1. Composition Stability Limits of Binary Semiconductor-Compounds.** ROBERT F. BREBRICK, *U. S. Naval Ordnance Laboratory* (introduced by F. Stern).—The composition stability limits of an essentially ordered, nondegenerate, semiconductor crystal $MN$ showing small deviations from the stoichiometric composition, are investigated under the conditions (1) that clustering of atomic point defects is unimportant, (2) the predominant atomic point defects are $M$ vacancies and $N$ vacancies, (3) each $M$ vacancy is associated with one acceptor level and each $N$ vacancy with one donor level, and (4) the coexisting condensed phase is one or the other of the pure elements $M$ or $N$. Expressions for the chemical potentials of the crystal components provide the starting point. Characterizing a limit of stability by the corresponding value of the net relative electron concentration, $(n-p)/2n_i$, analytical expressions are obtained for the stability limits. The magnitude of the stability range is larger the more negative the standard free energy of formation of the compound and the larger the intrinsic disorder ratio. The latter is the square root of the Schottky constant for ionized vacancies divided by the intrinsic carrier concentration. The effects of electrically active impurities are considered in the

approximation that the molar Gibbs free energy of the compound and its coexisting phase are not significantly altered. The result is a generalization of that obtained for the solubility of an electrically active impurity in a doped elemental semiconductor

**N2. Plastic Deformation of Highly Doped Dislocation-Free Germanium.** A. R. CHAUDHURI AND J. R. PATEL, *Raytheon Company* (sponsored by W. Crawford Dunlap, Jr.).—The plastic deformation of high purity dislocation-free germanium has shown that the yield strength of these crystals is lower than the theoretical strength. Germanium begins to show plasticity at about 350°C. The shear stress at this temperature is about 20 kg/mm², which is about an order of magnitude lower than the theoretical value of about $G/30$ or 170 kg/mm². It is believed that the low strength of these crystals is due to the presence of condensed vacancy loops. If the numbers of these loops do not change, the size should depend on the vacancy concentration. Since vacancies have an acceptor-type behavior in germanium, heavy doping with acceptor impurities should decrease the vacancy concentration and possibly alter the size of the loops. Crystals of dislocation-free germanium with about $10^{19}$/cm³ of gallium were tested in tension at 500°C, giving an upper yield stress of about 19 kg/mm². Crystals doped with about $7\times10^{18}$/cm³ of arsenic yielded under the same conditions at a stress of 8 kg/mm². Since the impurity concentration is quite similar in the two cases, the increased strength of the gallium doped crystals is most probably due to a decrease in the size of the condensed vacancy loops.

**N3. Thermoelectricity and Thermal Conductivity in the Lead Sulfide Group of Semiconductors.** D. GREIG, *National Research Council, Canada* (introduced by D. K. C. MacDonald).—The thermal conductivity, thermoelectric power, and electrical conductivity of six specimens of PbS and one each of PbSe and PbTe have been measured in the temperature range 4°K to 100°K. The samples varied from a natural galena one which was very highly polycrystalline to synthetic ones of each type containing only a few single crystals. Our previous measurements of thermoelectric power above 30°K had indicated no phonon drag effect in the carrier concentration range in which it is most pronounced in the elemental semiconductors. The present results however show the typical "drag" maxima in the thermoelectric power below 20°K in the specimens of highest charge carrier concentration. A rather detailed investigation of the phonon scattering processes is required to explain this phenomenon. The thermal conductivity was similar in all samples at 100°K but varied by as much as two orders of magnitude at 10°K. In order to explain both this and the thermoelectric power results, it has been necessary to consider dislocation and free electron scattering among the processes which restrict the flow of phonons.

**N4. Theory of Scattering of Phonons by Electrons in Donor States.** ROBERT W. KEYES, *Westinghouse Research Laboratories.*—The energy of an electron in a bound donor state of a semiconductor depends on the state of strain of the lattice.[1] Therefore, such bound electrons can provide a source of phonon scattering. The energy of the lowest electronic state associated with an arsenic impurity in germanium is a quadratic function of the strain.[1] Thus, the theory of the scattering of phonons by these states resembles the ordinary theories of scattering by point defects; for example, mass defects, and the electronic scattering can be described as a highly anisotropic Rayleigh scattering for long wavelengths. Apart from the anisotropy, the theory shows that for scattering by bound electrons the quantity $\Delta M$ of the theory of mass defect scattering must be replaced by $\Xi_u^2/gv^2\Delta_e$ where $\Xi_u$=deformation potential constant, $v$=velocity of sound, $\Delta_e$=chemical shift, and $g$=dimensionless numerical constant of order 30. Since $\Xi_u^2/\Delta_e=3\times10^5$ ev for arsenic in germanium, but $\Delta Mv^2$ is only 10 ev if $\Delta M$=mass of germanium atom, the scattering by bound electrons is very strong compared to other sources of point defect scattering.

[1] P. J. Price, Phys. Rev. 104, 1223 (1956).

**N5. Anisotropy of the Direct Phonon Relaxation Process of Donor Electrons in Silicon.** G. FEHER, *Bell Telephone Laboratories and Columbia University,* AND E. A. GERE AND D. K. WILSON, *Bell Telephone Laboratories.*—A direct phonon relaxation process in silicon and germanium has been calculated by Roth[1] and Hasegawa.[2] They predict an anisotropy in the relaxation rate $1/T_s$ which for silicon is proportional to $f(\theta)=\sin^2\theta(1+3\cos^2\theta)$, where $\theta$ is the angle between the [100] axis and the external magnetic field applied in the (110) plane. We have investigated the direct relaxation precess[3,4] in phosphorus doped silicon ($10^{15}$P/cm³) at 1.25°K and 8000 oe. The observed relaxation rate can be fitted with the expression $1/T_s=[0.9+0.4f(\theta)]\times10^{-3}$ sec$^{-1}$. The magnitude of the angle dependent part of the relaxation rate is in accord with theory[1,2] if one assumes for $|g||-g\perp|/g\cong10^{-2}$. These $g$ values are consistent with preliminary spin resonance experiments performed on the sample under strain. The theory does not account for the angle independent part[1,2] nor for the fact that, at 4.2°K and 3000 oe where Raman processes predominate,[4] the relaxation rate was found to be isotropic.[1]

[1] L. M. Roth, Bull. Am. Phys. Soc. Ser. II, 5, 50 (1960) and private communication.
[2] H. Hasegawa, Bull. Am. Phys. Soc. Ser. II, 5 (1960) and private communication.
[3] A. Honig and E. Stupp, Phys. Rev. Letters 1, 275 (1958).
[4] G. Feher and E. A. Gere, Phys. Rev. 114, 1245 (1959).

**N6. Mobility of an Electron in the Donor Impurity Band of a Compensated Semiconductor.** ALEXEI A. MARADUDIN,* *University of Maryland,* AND BARRY S. GOURARY,†‡ *Applied Physics Laboratory, Johns Hopkins University.*—The motion of an electron in an aperiodic one-dimensional potential consisting of a random linear array of attractive delta-function potentials of equal strength is studied. It is shown that the ground state of this electron is nondegenerate, and that its energy is separated from that of the next higher energy state by a gap. These two results imply that mobility in such a system is an activated process. The relevance of the present model to impurity band conduction in nearly compensated semiconductors is discussed, and its relation to the recent work of N. F. Mott is described.

* This research was supported by the Air Research and Development Command of the U. S. Air Force.
† Work supported by the Bureau of Ordnance, U. S. Department of the Navy.
‡ Present address: Westinghouse Research Laboratories, Pittsburgh 35, Pennsylvania.

**N7. Measurement of Microwave Hall Mobilities in Semiconductors.*** Y. NISHINA, S. H. LIU,† G. C. DANIELSON, AND R. H. GOOD, JR., *Iowa State University.*—A method of measuring the microwave Hall mobilities in semiconductors was described by Nishina and Spry.[1] This method utilizes a bimodal cavity with a sample attached on a wall. One mode of oscillation is excited externally and when a steady magnetic field is applied the other mode is induced by the Faraday rotation inside the sample. The relative intensity of the two modes determines the Hall mobility. Theoretical calculations were carried out to obtain the power ratio of the two modes in terms of the Hall mobility, the magnetic field and the dimensions of the cavity and the sample. Measurements were made on $n$- and $p$-type Ge samples at $X$-band frequencies between 29°K and 300°K in weak fields ($B\mu\ll1$). At room temperature the power ratio of the $n$-type samples followed the field and geometrical dependencies given by the calcula-

tions. The $p$-type samples exhibited the same type of dependence of Hall mobility on magnetic field as found by Willardson *et al.*[3]

* This work was supported by the U. S. Atomic Energy Commission.
† IBM Fellow, 1959–1960.
[1] Y. Nishina and W. J. Spry, J. Appl. Phys. 29, 230 (1958).
[2] R. K. Willardson, T. C. Harman, and A. C. Beer, Phys. Rev. 96, 1513 (1954).

**N8. Two-Carrier Theory of $p$-$n$ Junctions.** Y. F. CHANG, *Purdue University.*—The actual behaviour of $p$-$n$ junctions in the forward direction is far from the $\exp(\theta V)$ dependence predicted by the one-carrier theory, where $\theta = q/kT$. Germanium $p$-$n$ junctions exhibit an approximately $\exp(\theta V/1.66)$ dependence at low currents and an approximately $\exp(\theta V/2)$ dependence at high currents. Silicon diffused junctions exhibit approximately $\exp(\theta V/2)$ and $\exp(\theta V/1.5)$ dependencies at low and high currents, respectively. This preliminary study of the two-carrier theory is adequate to explain the various $\exp(\theta V/C)$ dependencies. Its essence is the consideration of the space-charge voltage due to the difference in electron and hole mobilities and of the $IR$-drop voltage across the bulk semiconductor material. The junction relations derived by Fletcher[1] and the boundary condition derived by this author[2] form the basis for this study.

[1] N. H. Fletcher, J. Electronics 2, 609 (1957).
[2] Y. F. Chang, Office of Naval Research Tech. Rept. 294 (Cruft Laboratory, 1959).

**N9. Hot Electron Emission from Germanium $p$-$n$ Junctions.*** R. E. SIMON AND W. E. SPICER, *RCA Laboratories.*—The external emission of hot electrons accelerated by the field in a reverse biased $p$-$n$ junction of germanium has been observed. The surface of the crystal had been treated with cesium to reduce the surface barrier. This effect is similar to that reported by Burton for silicon.[1] The threshold for photoemission for the cesium treated crystals was observed to be about 1.5 ev. Hot electron emission currents of $10^{-12}$ amp were observed with 2 v applied across the crystal. The emission saturated at about $10^{-5}$ with voltages of 10 v or higher. Photoemission induced by an internal electric field has been obtained from germanium.

* Work supported by U. S. Army Signal Corps.
[1] J. Burton, Phys. Rev. 108, 1342 (1957).

**N10. Photoemission Induced by an Internal Electric Field.*** W. E. SPICER AND R. E. SIMON, *RCA Laboratories.*—The external emission of photo-induced carriers from cesium treated silicon by means of the internal field across a $p$-$n$ junction has been observed and studied. The impinging radiation creates electrons in the $p$-type material. These diffuse to the surface and receive sufficient energy from the internal field at the $p$-$n$ junction to escape over the surface barrier. The spectral response of the photoemission can be fitted to a simple relationship containing the optical absorption coefficients of Si and diffusion length. The threshold of response is that of the band gap of Si (1.05 ev). Similar emission has been observed from Ge and this data will be presented.

* Work supported by U. S. Army Signal Corps.

**N11. Measurement of Minority Carrier Diffusion Lengths in $p$-$n$ Junctions by Analyzing Photovoltaic Spectral Response Curves.*** JOSEPH J. LOFERSKI AND JOSEPH J. WYSOCKI, *RCA Laboratories.*—If the absolute value of absorption constant $\alpha$ of a semiconductor is known as a function of photon energy $h\nu$, it is possible to calculate the shape of the spectral response of a photovoltaic cell with a specified geometry, minority carrier diffusion lengths ($L_n$ and $L_p$), and surface recombination velocity. Consequently, if one establishes the position of the $p$-$n$ junction by some independent means, one can estimate $L_n$ and $L_p$ from the shape of the spectral response curve of the junction.[1] Representative theoretical curves of response versus $\alpha$ for various plausible combinations of semiconductor parameters have been calculated. Experimental photovoltaic spectral response curves of diffused germanium and silicon $p$-$n$ junction photocells have been used to verify the theory. Similar curves taken on GaAs cells with different junction depths have been used to estimate $L_n$ and $L_p$.

* This work was performed under contract with the U. S. Army Signal Research and Development Laboratories.
[1] A. M. Goodman, RCA Laboratories, has proposed making such measurements by analyzing surface photovoltage spectral response curves (private communication).

**N12. Pressure Dependence of the Reverse Characteristic of a Germanium Esaki Diode.*** MARSHALL I. NATHAN AND S. L. MILLER, *International Business Machines Corporation,* AND LEONARD FINEGOLD, *Harvard University.*—The pressure dependence of the reverse current-voltage characteristic of a germanium Esaki diode has been measured at room temperature to 28 000 kg/cm². The diode was alloyed with an InGa dot on an Sb-doped substrate; peak current density $\cong 0.04$ amp/cm². At atmospheric pressure the $I$-$V$ curve at 4.2°K shows that almost all the tunneling in the forward direction is phonon assisted. The "Morgan-Kane kink,"[1] which indicates the onset of direct tunneling between the (000) edges of the valence and conduction bands, is observed at 4.2°K and 77°K but not at room temperature. The pressure coefficients for the energies of the (000) and the (111) conduction band minima relative to the valence band are known. Since these coefficients are different, the pressure changes of the phonon-assisted and the direct-tunneling currents will be different. Hence from the pressure dependence of the $I$-$V$ curve it is possible to observe the presence of direct tunneling at room temperature. The Morgan-Kane picture is confirmed by the pressure data. The data indicate that direct-tunneling current is in the range of 3 to 8 times phonon-assisted current at atmospheric pressure for $-V \gtrsim 0.2$v.

* Supported in part by the Office of Naval Research.
[1] J. V. Morgan and E. O. Kane, Phys. Rev. Letters 3, 466 (1959).

**N13. Further Characteristics of the Solid-State Ionization Chamber.** R. J. GRAINGER, J. W. MAYER, J. S. WIGGINS, AND S. S. FRIEDLAND, *Hughes Aircraft Company.*—The response of high-resistivity shallow diffused silicon diodes to charged particles has been reported previously.[1,2] The width of the depletion region, which depends on (bulk resistivity × applied bias)$^{\frac{1}{2}}$, determines the sensitive volue of the detector. 6000 ohm-cm units operated at $\cong$200-v reverse bias were found to have a response proportional to proton energy up to 9 Mev. These same units responded linearly to electrons from the internal conversion lines of $Cs^{137}$, $Cs^{134}$, and others. The data indicates that within experimental limits ($\cong 2\%$), the detectors respond linearly to the energy of particles whose mass varied from electron mass to the mass of carbon ions and fission fragments. Using a detector with area of 2 mm², the width of the pulse-height distribution at half-maximum was measured to be 17.5 kev for natural alpha particles. The scattering of protons from Al and Be yielded resolutions of approximately 1%. This was sufficient to resolve the nuclear levels. Discussion of the resolution of large area units will be presented.

* This work supported in part by the Defense Atomic Support Agency.
[1] S. S. Friedland, J. W. Mayer, and J. S. Wiggins, Nucleonics 18, 54 (1960).
[2] S. S. Friedland, J. W. Mayer, J. M. Denney, and F. Keywell, Rev. Sci. Instr. 31, 74 (1960).

TUESDAY AFTERNOON AT 2:00

Exhibit Hall

(D. W. KERST presiding)

***Post-Deadline Papers, If Any***

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TUESDAY AFTERNOON AT 2:00

Continental Room

(H. E. GOVE presiding)

***Nuclear Interactions III***

**P1. Lifetimes of the 668- and 961-kev Excited States of $Cu^{63}$.*** T. ROTHEM, E. R. METZGER, AND C. P. SWANN, *Bartol Research Foundation.*—Nuclear resonance scattering from the 668-kev and 961-kev levels of $Cu^{63}$ has been observed. $Zn^{63}$ was prepared by bombarding copper targets for one hour with 5.1-Mev protons at a current of 10 $\mu$a in the Bartol-ONR electrostatic generator. The $Zn^{63}$ together with Zn carrier was distilled into a quartz ampoule of $\approx$1.5-ml volume which was then sealed off. The source was kept in the gaseous phase by heating the ampoule to 950°C throughout the experiment. From the magnitude of the resonance scattering measured at two angles and on the basis of the presently accepted decay scheme,[1] preliminary values of $3.1\times10^{-13}$ and $9\times10^{-13}$ sec were obtained for the mean lives of the 668-kev state and the 961-kev state, respectively. The angular distribution of the 668-kev resonance radiation was found to be approximately isotropic. For the coefficient $A_2$ in the distribution $W(\theta)=1+A_2P_2(\cos\theta)$ of the 961-kev resonance radiation a value $A_2=0.8\pm0.2$ was measured.

* Assisted by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Ricci, Girgis, and van Lieshout, Nuovo cimento 11, 156 (1959).

**P2. Possible $0^+$ States in $Zn^{64}$, $Zn^{66}$, and $Zn^{68}$.*** D. M. VAN PATTER, N. NATH, AND M. A. ROTHMAN, *Bartol Research Foundation of the Franklin Institute.*—Gamma-ray spectra from the $Zn(n,n'\gamma)$ reaction have been observed for $E_n=1.0$–3.3 Mev. For $E_n>2.8$ Mev, the spectra become complicated, with at least ten $\gamma$ rays or composite groups. Comparison of experimental cross sections with theory[1] indicate spin 2 for the first two levels of, $Zn^{64}$ $Zn^{66}$, and $Zn^{68}$ (omitting the possible 1.60-Mev state[2] in $Zn^{68}$. A composite 1.30-Mev $\gamma$-ray group was observed, corresponding to the decay of states at $2.29\pm0.02$, 2.37,[3] and 2.32[4] Mev in $Zn^{64}$, $Zn^{66}$, and $Zn^{68}$. In agreement with recent radioactivity results,[2,4] no ground-state transition was seen. The observed excitation function is best fitted by assuming spin zero for these states; while this assignment is not unique, spins 1, 2, or 3 seem to be unlikely. Evaluation of present evidence including radioactivity suggests that the level near 2.3 Mev in each isotope may have spin 0+, with the possible exception[4] of $Zn^{68}$. Evidence was also found for a level at about 2.8 Mev in each isotope. These states have been observed in the $(p,p')$ reaction,[2] but not in radioactive decays. Gamma rays corresponding to transitions to the ground state and first level were seen.

* Assisted by the U. S. Atomic Energy Commission.
[1] D. M. Van Patter, Bull. Am. Phys. Soc. Ser. II, 5, 76 (1960).
[2] B. Beurtey *et al.*, Nuclear Phys. 13, 397 (1959).
[3] A. Schwarzschild (private communication).
[4] D. J. Horen, Phys. Rev. 113, 572 (1959).

**P3. Spin Determinations from the $(n,n')$ Reaction for Even-Even Nuclei, $A=70$–100.*** S. S. MALIK, *Ohio University,*† AND D. M. VAN PATTER, *Bartol Research Foundation.*—Hauser-Feshbach calculations for the $(n,n')$ reaction have been performed for fifteen of the even-even isotopes of Ge, Se, Zr, and Mo for $E_n=2.67$ Mev, using the transmission coefficients calculated by Emmerich.[1] The theoretical cross sections so obtained have been compared with the results of a $(n,n'\gamma)$ survey[2] for these elements. For second excited states, the predicted difference in cross sections makes it possible to distinguish between spins of 2+ and 4+. An attempt has been made to extend these calculations to higher excited states. However, the experimental $(n,n'\gamma)$ spectra are complicated because of the presence of several isotopes and interfering effects from $\gamma$-ray cascades. Therefore, the results of such a comparison do not, in general, distinguish between spin possibilities of 2+ and 4+ for higher states. Possible spin evaluations based on this method will be discussed for some of the nuclei under consideration.

* Assisted in part by the U. S. Atomic Energy Commission.
† One of the authors (S. S. Malik) gratefully acknowledges the help of Dr. L. J. Gallaher for writing up the computer program.
[1] W. S. Emmerich, Westinghouse Research Rept. 60-94511-6-R19 (April, 1958).
[2] S. S. Malik, C. E. Mandeville, N. Nath, M. A. Rothman, and D. M. Van Patter, Bull. Am. Phys. Soc. Ser. II, 4, 259 (1959).

**P4. $(\alpha,n)$ Cross Sections for Ni, Cu, and Zn Nuclei.** P. H. STELSON AND F. K. MCGOWAN, *Oak Ridge National Laboratory.*—Thick-target $(\alpha,n)$ neutron yields have been measured from threshold to about 11-Mev $\alpha$-particle energy for isotopically enriched targets of nickel, copper, and zinc. The absolute neutron yields, which were measured at approximately 100-kev energy intervals, have an accuracy of $\pm4\%$. The neutron detector was the $4\pi$, flat-energy response graphite sphere detector developed by Macklin.[1] Cross sections for the $(\alpha,n)$ reaction were obtained to an accuracy of $\pm15\%$ by differentiation of the smooth thick-target yield curves. Values for the measured cross sections varied from 50 $\mu$b for $Cu^{65}$ near threshold to over 100 mb for most of the nuclei at 10-Mev $\alpha$-particle energy. For those nuclei in which the $(\alpha,n)$ cross section is thought to account for most of the reaction cross section, the observed cross sections are considerably larger than those predicted by Shapiro[2] for his larger radial parameter of 1.5 $A^{\frac{1}{3}}\times10^{-13}$ cm. Both the shape and absolute values of the observed cross sections agree well with the recent optical-model analysis of reaction cross sections for $\alpha$ particles by Igo.[3]

[1] J. H. Gibbons and R. L. Macklin, Phys. Rev. 114, 571 (1959).
[2] M. M. Shapiro, Phys. Rev. 90, 171 (1953).
[3] George Igo, Phys. Rev. 115, 1665 (1959).

**P5. Total Reaction Cross Section for $\alpha$ Particles on $Ni^{58}$.** F. K. MCGOWAN, P. H. STELSON, AND W. G. SMITH,* *Oak Ridge National Laboratory.*—Thick-target yields have been measured for the $(\alpha,\gamma)$ reaction from 4.9–6.1 Mev, the $(\alpha,p)$

reaction from 4.9–11.1 Mev, and the $(\alpha,n)$ reaction from threshold (10.49±0.03 Mev) to 11.3 Mev using isotopically enriched $Ni^{58}$ targets. The $(\alpha,\gamma)$ and $(\alpha,p)$ reactions were identified by measuring the coincident annihilation radiation from the induced $\beta^+$ activities. The absolute thick-target yields, which were measured at approximately 100-kev energy intervals, have an accuracy of ±6% (aside from possible uncertainties in the branching ratio $\beta^+/\epsilon$ for the $Zn^{62}$ and $Cu^{61}$ activities). The partial reaction cross sections were obtained to an accuracy of ±15% by differentiation of the smooth thick-target yield curves. Over the measured energy range, the cross sections increase from 1–12 μb for the $(\alpha,\gamma)$ reaction, 0.6 μb–316 mb for the $(\alpha,p)$ reaction, and 7.7–16.7 mb for the $(\alpha,n)$ reaction between $E_\alpha=10.8$ and 11.3 Mev. At $E_\alpha=5$ and 10 Mev, the reaction cross section is 7 and 1.5 times smaller than that predicted by a calculation[1] using an optical-model potential obtained from the analysis of elastic scattering data.

* Summer research participant from Purdue University.
[1] George Igo, Phys. Rev. 115, 1665 (1959).

**P6. Excitation Function for $Ni^{58}(p,pn)Ni^{57}$, $Ni^{58}(p,\alpha)Co^{55}$, and $Ni^{64}(p,n)Cu^{64}$ Reactions.** J. J. PINAJIAN, J. L. NEED, AND W. H. WEBB, *Oak Ridge National Laboratory.**—Excitation functions were obtained by activation of nickel foils, of natural isotopic abundance, with 4- to 23-Mev protons in the deflected beam of the ORNL 86-in. cyclotron. Nickel, cobalt, and copper were separated by ion-exchange and were further purified by chemical processing. Absolute cross sections were obtained by beta- and gamma-counting. The magnitude of these cross sections relative to the total cross sections for the formation of the compound nucleus is compared with the predictions based on the statistical model.

* Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

**P7. Evaporation of Protons in Coincidence in Alpha-Particle Bombardment of $Ni^{58}$.*** D. BODANSKY,† R. C. COLE,‡ W. G. CROSS,§ C. R. GRUHN, AND I. HALPERN, *University of Washington.*—A pair of two-counter telescopes was used to study angular energy distributions and correlations of coincident pairs of protons emitted in alpha-particle bombardments of nickel and iron isotopes. The most extensive results were obtained for $Ni^{58}$ at 32 Mev. Here $\sigma\cong0.55$ barns for reactions in which at least two protons are emitted. The proton spectra are peaked between 4 and 5 Mev. At higher energies they can be represented by the form $E\exp(-E/T)$. $T$ is about 1.7 Mev for spectra obtained with both counters perpendicular to the beam. The energies of coincident protons are to good approximation uncorrelated. The angular distributions are strongly anisotropic. The c.m. cross section with both counters at 30° or 150° to the beam is about twice as large as with both counters at 90°. These and other features of the observed distributions suggest that the protons are being evaporated from compound nuclei. The large anisotropies arise from the large average angular momenta of these nuclei.

* Supported in part by the U. S. Atomic Energy Commission.
† Now on leave at the Institute for Theoretical Physics, Copenhagen.
‡ Now at University of California at Los Angeles.
§ On leave from Chalk River Laboratories.

**P8. $Zr^{90}(d,p)Zr^{91}$ Reaction.** R. L. PRESTON, H. J. MARTIN, AND M. B. SAMPSON, *Indiana University.**—Enriched $ZrO_2$ targets, 98.6% $Zr^{90}$, were bombarded by 10.8-Mev deuterons from the Indiana University cyclotron. The outgoing protons were analyzed by a 180° double-focusing magnetic spectrometer, and angular distributions were obtained for proton groups at $Q$ values of 4.98, 3.79, and 2.91 Mev. The highest energy group corresponds to the ground state of $Zr^{91}$ and has an $l=2$ angular distribution, in agreement with the $2d_{5/2}$ assignment for the 51st neutron. The proton group corresponding to the 1.2-Mev state in $Zr^{91}$ has an $l=0$ angular distribution. This is in agreement with measurements reported by Cohen and Price.[1] This level is, presumably, the $3s_{1/2}$ neutron state. The $Q=2.91$-Mev proton group corresponds to two closely spaced levels in $Zr^{91}$ at an excitation energy of about 2.1 Mev.

* Work supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] B. L. Cohen and R. E. Price (to be published).

**P9. $Zr^{91}(d,p)Zr^{92}$ Reaction.** H. J. MARTIN, R. L. PRESTON, AND M. B. SAMPSON, *Indiana University.**—Measurements similar to those reported in the preceding abstract were performed on a $ZrO_2$ target, enriched in $Zr^{91}$ (86.9% $Zr^{91}$). Proton groups were found at $Q$ values of 6.44, 5.50, 4.94, and 4.37 Mev, corresponding to states in $Zr^{92}$ at excitation energies of 0, 0.94, 1.50, and 2.07 Mev. A weak proton group with a $Q$ value of about 4.5 Mev appears to correspond to the 1.8-Mev state in $Zr^{92}$. The angular distributions, and the cross sections of these proton groups will be compared with the $Zr^{90}(d,p)Zr^{91}$ data. The data will be used to advance an interpretation of the states in $Zr^{92}$ as being made up largely from two-neutron configurations such as $(d_{5/2})^2$, $(d_{5/2}\ s_{1/2})$, etc. The ground state and 0.94-Mev state in $Zr^{92}$ appear to be the $0^+$ and $2^+$ states of the $(d_{5/2})^2$ configuration. Possible assignments for the other states will be discussed.

* Work supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

**P10. Isomer Yields in the $Cd^{116}(p,pn)Cd^{115}$ Reaction.** SHELDON KAUFMAN, *Princeton University.*—Natural cadmium was bombarded at the Nevis cyclotron of Columbia University with 380-Mev protons. Silver was chemically separated soon after the end of the bombardment in order to determine the contribution to the $Cd^{115}$ yield of 20-min $Ag^{115}$ formed in the $Cd^{116}(p,2p)$ reaction. The measured cross sections are: $Cd^{115g}$ ($I=\frac{1}{2}+$), 41 mb; $Cd^{115m}$ ($I=11/2-$), 26 mb; $Ag^{115g}$ ($I=7/2+$), 20 mb. The $Ag^{115g}$ cross section includes the fraction of 20-sec $Ag^{115m}$ which decays by isomeric transition. The ratio $\sigma_m/\sigma_g$ for the $Cd^{116}(p,pn)Cd^{115}$ reaction is 0.65±0.1. This ratio was also measured at 19 Mev, just above the threshold, with the result 0.4±0.1. The ratio when $Cd^{115}$ is formed in other high-energy reactions[1] is in the range 2.0–3.0. These results will be discussed in terms of the difference in mechanism of the $(p,pn)$ and more complex reactions.

[1] P. Kruger and N. Sugarman, Phys. Rev. 99, 1459 (1955).

**P11. Nuclear Structure Studies in the Tin Isotopes with $(d,p)$, $(d,t)$, and $(d,d')$ Reactions.*** BERNARD L. COHEN AND ROBERT E. PRICE, *University of Pittsburgh.*—$(d,p)$ and $(d,t)$ reactions in the even isotopes of Sn excite one principal nuclear level for each single particle level in the $50<N\leq82$ neutron shell. The same levels are strongly excited by both $(d,p)$ and $(d,t)$ reactions which indicates that, in the ground states of the even isotopes, all subshells are partly full as predicted by pairing theory rather than some being completely full and others empty as in simple theory. The principal $d_{5/2}$ and $g_{7/2}$ states remain at the same excitation energy in all isotopes; the $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ states shift somewhat more so that each is the ground state in some isotopes. While the level structure is strikingly similar in all odd-neutron isotopes of $_{50}Sn$, it is very different from these in odd-neutron isotopes of $_{48}Cd$, even where the neutron number is the same. The fine structure of the anomalous peaks in $Sn(d,d')$ reactions was studied. The lower energy component (~2.0 Mev) is essentially a single strong level, but the higher energy component (~2.8 Mev) differs radically among the isotopes, sometimes being a strong single peak ($A=116$, 119, 124) and sometimes consisting of many smaller peaks. There is no energy variation with mass as in the Zn isotopes. The structure reported at ~5 Mev excitation[1] was not found.

* Supported by National Science Foundation and joint program of Office of Naval Research and U. S. Atomic Energy Commission.
[1] J. L. Yntema and B. Zeidman, Phys. Rev. 114, 815 (1959).

TUESDAY AFTERNOON AT 2:00

Burgundy Room

(ROBERT SERBER presiding)

## *Theoretical Physics IV: Collision Processes*

**PA1. $p$-$p$ Modified Phase Shift Analysis from 1.4–210 Mev.*** M. H. MACGREGOR, M. J. MORAVCSIK, AND H. P. NOYES, *Lawrence Radiation Laboratory, Livermore.*—A modified phase shift analysis,[1] in which low angular momentum state phase shifts are searched on and high angular momentum states are calculated from the one-pion exchange pole in the scattering amplitude, has been used to analyze $p$-$p$ scattering data from 1.4 to 68 Mev and at 147 Mev and 210 Mev. The addition of the pole term to the search problem did not alter materially the results of earlier analyses[2] of low-energy (1.8–40 Mev) $p$-$p$ data; that is, the ambiguity arising from insufficient data still exists. Triple scattering experiments are required even at low energies. The most interesting results were obtained at 210 Mev, where the $\sigma$, $P$, $R$, and $A$ Rochester data have proved to be sufficient to restrict the acceptable phase shift solution sets to a small number, just as was the case at 310 Mev.[3] Energy dependence of the phase shifts will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] P. Cziffra, M. H. MacGregor, M. J. Moravcsik, and H. P. Stapp, Phys. Rev. 114, 880 (1959).
[2] H. P. Noyes and M. H. MacGregor, Phys. Rev. 111, 223 (1958); M. H. MacGregor, Phys. Rev. 113, 1559 (1959).
[3] M. H. MacGregor, M. J. Moravcsik, and H. P. Stapp, Phys. Rev. 116, 1248 (1959).

**PA2. Nucleon-Nucleon Phase Parameters at Energies from 9-340 Mev.*** M. H. HULL, JR., G. BREIT, K. LASSILA, K. D. PYATT, JR., AND H. RUPPEL, *Yale University.*—The previously reported[1] phase shift analysis simultaneously employing data at most available energies from 9 to 340 Mev has been continued. Gradient searches with previous starting points have been reinvestigated; an additional $n$-$p$ starting point has been constructed using unpublished Gammel-Thaler values.[2] The normalized weighted sum of squares of deviations from experiment changed from 20 to 3 in the $p$-$p$ cases, and from 50 to 2 in the $n$-$p$. Agreement[3] with charge independence has been confirmed with additional data regarding stability of one-pion exchange parameters (OPE) to search procedure. Evidence for correctness of OPE mixture of $S_{12}$ and $\sigma_1 \cdot \sigma_2$ terms has been obtained. Uncertainties in phase shifts range from 0.002 to 0.02 radian such as $0.8 \pm 0.003$, $0.4 \pm 0.01$, $0.08 \pm 0.01$, $-0.12 \pm 0.02$ for $^1S_0$ at 40, 100, 200, and 300 Mev, respectively.

* Supported by Office of Ordnance Research, U. S. Army, and the by U. S. Atomic Energy Commission.
[1] G. Breit, Proc. London Conference on Nuclear Forces and the Few Nucleon Problem (July, 1959) (to be published).
[2] J. Gammel and R. M. Thaler (private communication).
[3] G. Breit, M. H. Hull, Jr., K. Lassila, and K. D. Pyatt, Jr., Phys. Rev. Letters 4, 79 (1960).

**PA3. Phase Shift Analysis of Proton-Proton Scattering near 150 Mev.*†** EDWARD PRENOWITZ AND J. N. PALMIERI, *Harvard University.*—An investigation of sets of phase shifts which describe proton-proton scattering experiments performed at energies between 140 and 150 Mev is in progress. The set of data used consists of about 70 values of $d\sigma/d\Omega$, $P$, $D$, and $R$. The grid method of search was used for phase shifts up to and including $F$ waves; the one-pion exchange term[1] was included to approximate higher order phase shifts. Adjustments have been made starting from the Gammel-Thaler phase shifts[2] and from sets similar to solution 2 and to solution 6 of Stapp *et al.*[3] The effect of the one pion exchange term and the treatment of experimental errors will be discussed. It is hoped that solutions resulting from random sets can be presented.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† This work was performed in part at the MIT Computation Center, Cambridge, Massachusetts.
[1] P. Cziffra, M. H. MacGregor, M. J. Moravcsik, and H. P. Stapp, Phys. Rev. 114, 880 (1959).
[2] J. L. Gammel and R. M. Thaler, Phys. Rev. 107, 291 (1957).
[3] H. P. Stapp, T. J. Ypsilantis, and N. Metropolis, Phys. Rev. 105, 302 (1957).

**PA4. $\pi$-Deuteron Scattering in the Dinucleon Formalism.** WILLIAM FRANK AND THURMAN E. SPRIGGS, *U. S. Naval Ordnance Laboratory.*—The Chew-Low formalism for the fixed two-nucleon meson system[1] has been applied to the calculation of the elastic and inelastic cross sections for the scattering of 0- to 250-Mev pions from deuterons. The incident pion is viewed as scattered by the adiabatically varying cloud of instantaneously fixed nucleons. This point of view is justified for the deuteron and not too energetic final states. One can derive an expression for the derivative of the matrix element describing scattering by two fixed nucleons. This provides an equation for the determination of this amplitude. A modified crossing theorem is found to apply. The asymptotic behavior with respect to nuclear separation can be found and results in an expansion in the number of exchanged mesons. Results can be expressed directly in terms of one nucleon scattering data independently of any impulse approximation. Results will be discussed.

[1] W. Frank, Ann. Phys. (to be published).

**PA5. Analytic Properties of Partial Wave Amplitudes in Yukawa Potential Scattering.*** DANIEL I. FIVEL AND ABRAHAM KLEIN, *University of Pennsylvania.*—The dispersion relation for the $l$th partial wave amplitude $A_l$ for Yukawa potential scattering previously has been derived from the Mandelstam representation for the scattering amplitude. We have obtained a direct proof of the required analyticity properties of $A_l$. With $k$=wave number, we write $A_l(k) = (2ik)^{-1} \times [f_l(k) f_l^{-1}(-k) - 1]$ where $f_l(k)$ is related to a solution of the radial Schrödinger equation satisfying asymptotic boundary conditions. It also is known that $f_l(-k)$ is analytic in Im $k > 0$ and vanishes only for a finite set of points which all lie on Re $k = 0$. We have investigated the properties of $f_l(k)$ by rewriting the integral equation which it satisfies as a Volterra equation on a finite interval, in which the contribution from the asymptotic range of the integral is absorbed into the inhomogeneous term. The integrals occurring in the Neumann series for the inhomogeneous term are shown to possess analytic continuations into Im $k > 0$ excluding the cut Im $k > \mu/2$, Re $k = 0$ where $\mu^{-1}$ is the range of the potential. The uniform convergence of the series is established utilizing the approximations which apply in the asymptotic region. The analyticity of $f_l(k)$ in the same cut region then follows from the convergence properties of the Neumann series for Volterra equations.

* Supported in part by the U. S. Atomic Energy Commission.

**PA6. Pion-Nucleon Scattering in the Mandelstam Representation.*** S. C. FRAUTSCHI AND J. D. WALECKA, *University of California and Stanford University.*—We have studied the

dispersion relation which one obtains from the Mandelstam representation for the $T=\frac{1}{2}$, $J=\frac{1}{2}$ state in pion-nucleon scattering.[1,2] Unlike the static Chew-Low theory, thus fully relativistic theory allows in principle a calculation of the position of the resonance. It also allows one to include the effect of pion-pion interaction. Specifically, we have investigated the effect of the proposed pion-pion resonance in the $T=1$, $J=1$ state.[3]

* Supported by the National Science Foundation.
[1] S. W. MacDowell, Phys. Rev. 116, 774 (1959).
[2] W. R. Frazer (preprint).
[3] W. R. Frazer and J. R. Fulco, Phys. Rev. Letters 2, 365 (1959).

**PA7. $\pi$-Nucleon Scattering with $\pi$-$\pi$ Interaction.** M. H. Cha and W. Frank, *U. S. Naval Ordnance Laboratory.*—A semiclassical calculation is performed to determine the effect of a $\pi$-$\pi$ interaction on the scattering of high-energy pions from nucleons. Pions are assumed to interact with a fixed nucleon by means of gradient coupling. Absorption of an incident pion by a nucleon induces a precission of its spin and isotopic spin. This is calculated readily from the equations of motion for spin and isotopic spin operators in the Heisenberg representation. The precessing spin and isotopic spin radiate mesons whose propagation is distorted by the nonlinear $\pi$-$\pi$ interaction. An effective nonlinear coupling between isotopic spin modes of the meson results. Neglect of reabsorption of the radiated mesons through the $\pi$-$\pi$ interaction leads to linear equations. A number of approximations can be applied to the solution of these equations. An estimate also can be found for reabsorption effects. The effect of modulation of the incident wave by the $\pi$-$\pi$ interaction is considered. Results will be reported.

**PA8. Scattering at Low Energies.*** Leonard Rosenberg and Larry Spruch, *New York University.*—Recently developed techniques for obtaining upper bounds on scattering lengths have been extended, in the particular case of central potentials, to provide bounds on phase shifts at nonzero energies. In the zero-energy case a bound on the error term in the variational expression was obtained using the minimum property of the Rayleigh-Ritz principle. Negative energy states, when they exist, must be taken into account.[1] For positive energy scattering, with cutoff potentials, the energy eigenvalue problem considered is that obtained by placing the system in a box. Again, the effect of bound states, including those with positive energies which lie below the scattering energy considered, may be subtracted off so that a variational calculation gives a lower bound on the phase shift. The formal results are similar to those found by Percival. As in footnote 1, applications of these results to many-body scattering problems can be found. For central potentials, upper bounds may also be obtained.

* Sponsored by both the Geophysics Research Directorate of the U. S. Air Force Cambridge Research Center and the Office of Ordnance Research, U. S. Army.
[1] L. Rosenberg, L. Spruch, and T. F. O'Malley, Phys. Rev. (to be published).

**PA9. High-Energy Scattering Approximation.*** B. J. Malenka, *Tufts University,* and H. S. Valk,† *University of Oregon.*—A high-energy small-angle approximation of the type discussed by Glauber[1] for the diffraction scattering of an elementary particle is considered. In this approximation, an attempt is made to separate the relatively short-range interaction contribution to elastic scattering from the better known long-range effects. A method being investigated involves projecting out the long-range $S$-wave part of the scattering amplitude and replacing this by a term which phenomenologically represents the short-range contribution. This procedure correctly preserves the relative phase relations. The possible representation of the short-range effects in terms of an effective range and the application to pion-nucleon scattering is under consideration.

* Partially supported by the U. S. Atomic Energy Commission.
† Temporary address: National Science Foundation, Washington D. C.
[1] R. J. Galuber, *Lectures in Theoretical Physics* (Interscience Publishers, Inc., New York, 1958), Vol. I.

**PA10. High-Energy Scattering by Compound Systems.*** D. J. Kleitman and R. J. Glauber, *Harvard University.*—At sufficiently high energy, the small-angle scattering of a particle by a potential that can be decomposed into two parts may be described completely by an expression which involves only the amplitudes for single scatterings by the individual parts and double scattering by both of them.[1] The double-scattering term requires a knowledge only of the scattering amplitudes on the energy shell. The appearance of this result is surprisingly simple when compared with the formal multiple-scattering expansion, since it holds for systems for which triple scattering is nonnegligible and for which off-energy-shell propagation in intermediate states must be taken into account. Examples of such systems are given. The simplifications are due to cancellations which take place in the high-energy limit. This result shows that the only multiple-scattering corrections to the impulse approximation for small-angle deuteron cross sections at high energies will be due to double scattering with energy conserved in the intermediate state. It suggests that these may be the leading corrections at lower energies.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] R. J. Glauber, *Lectures in Theoretical Physics* (Interscience Publishers, Inc., New York 1959), Vol. I, p. 315.

**PA11. Effect of Multiple Scattering on Pickup Reactions.** T. F. Tuan, *Northwestern University,* R. H. Bassel, *Oak Ridge National Laboratory,* and R. M. Drisko, *University of Pittsburgh.*—A calculation for pickup reaction at high energies, including the second-order (multiple-scattering) processes is made on the belief that pickup can only occur classically at high energies if the incident particle can transfer sufficient momentum to the bound particle so that it may acquire a velocity comparable to that of the incident particle before being captured. This classical process is precisely analogous to one of the four second-order Feynman diagrams where all double scattering is taken into consideration. A unique "Born" expansion scheme for rearrangement collisions has been used for the special case of a proton incident on a deuteron target. By assuming a Yukawa potential and the Hulthen wave function, analytic expressions for the second-order matrix elements at high incident proton energies may be obtained. There is a pole in the second-order matrix element due to the vanishing of the energy denominator at $\theta_{c.m.} \sim \pi$ which makes it go down more slowly with incident energy than the first "Born." Thus it would seem that, in analogy with classical results, the second "Born" should predominate at high energies. This would also account for the considerable capture at large angles.

**PA12. Angular Momentum and the Description of Three-Body Collisions.*** Felix T. Smith. *Stanford Research Institute.*—With short-range forces, initial and final states in a classical three-body collision are straight-line trajectories into and out of a region where all three particles are close together at the same time. By using six coordinates, three describing the relative position of a pair of particles, and three the relative position of the third particle and the center of mass of the pair, the condition for simultaneous togetherness can be expressed with the help of the 6×6 *grand angular momentum tensor,* whose components are $\Lambda_{ij}=(m_i/m_j)^{\frac{1}{2}}x_ip_j-(m_j/m_i)^{\frac{1}{2}}x_jp_i$. For a close three-body collision $\Lambda^2=\frac{1}{2}\Sigma_{i,j}\Lambda_{ij}^2$ must be small. $\Lambda^2$ commutes with the ordinary angular momentum operators and with the kinetic energy; its eigenvalues are $\lambda(\lambda+4)\hbar^2$, with integral $\lambda$, and its eigenfunctions hyperspherical harmonics. Initial and final three-body states can be described quantally by the tota

energy $E$, $A^2$, and a commuting set of ordinary angular momenta; this description has the same relation to a momentum representation that the angular momentum analysis of a two-body collision has to a momentum representation.

* Supported by National Aeronautics and Space Administration.

**PA13. Some Results from the Special Theory of Relativity.** M. Z. v. KRZYWOBLOCKI, *University of Illinois.**—The author derives a form of the special theory of relativity equations when the velocity of light is not a constant quantity. It may take different values in both references systems. The method is applied to the case of a Čerenkov (or Vavilov-Čerenkov) effect when the velocity of motion is greater than the velocity of light in the medium in question. To formulate analytically this phenomenon, two transformations of coordinates are necessary. By means of reduction coefficients the super-light motion can be expressed analytically by means of generalized equations analogous to the equations of motion in the ordinary classical theory of relativity.

* This paper placed on Tuesday at the author's request.

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## WEDNESDAY MORNING AT 9:30

## Caribar-Mural Room

## (G. M. TEMMER presiding)

### *Nuclear Interactions IV*

**Q1. Cross Sections for $(\alpha,\alpha n)$ and $(\alpha,2pn)$ Reactions on $Ce^{142}$.*** BRUCE M. FOREMAN, JR., *Brookhaven National Laboratory.*—Cross sections have been measured radiochemically for the nuclear reactions $Ce^{142}(\alpha,\alpha n)Ce^{141}$ and $Ce^{142}(\alpha,2pn)Ce^{140}$ in the helium-ion energy range 17–41 Mev. The cross section for the $(\alpha,\alpha n)$ reaction begins to rise sharply at about 25 Mev and reaches a value of $62\pm5$ mb at 41.1 Mev. The cross section for the $(\alpha,2pn)$ reaction begins to rise at 32 Mev and reaches a value of $2.5\pm0.5$ mb at 41.1 Mev. An upper limit to the cross section for the $Ce^{142}(\alpha,\alpha p)La^{141}$ reaction of less than 0.1 mb at all energies covered also has been obtained. The results for the $(\alpha,\alpha n)$ reaction are discussed in terms of these possible mechanisms: compound nucleus formation and decay, direct inelastic scattering followed by neutron evaporation, and knock-on. The most likely mechanism appears to be that of direct inelastic scattering followed by neutron evaporation. The existence of a measurable cross section for the $(\alpha,2pn)$ reaction in this energy region suggests that the reaction proceeds mainly by $He^3$ emission, probably by a stripping mechanism. These results are consistent with the hypothesis that in this energy range, at most one particle is emitted as a result of direct interaction.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

**Q2. Photonuclear Measurements with Monoenergetic Gamma Rays.** ROBERT E. WELSH* AND D. J. DONAHUE, *The Pennsylvania State University.*—Monoenergetic gamma rays produced by capture of thermal neutrons in various materials have been used to study the reactions $Ta^{181}(\gamma,n)Ta^{180(m)}$ (8.15 hr) and $Au^{197}(\gamma,n)Au^{196}$ (5.6 day). Samples of such gamma emitters (including Ni, Al, Fe, Cr, Cu, Co, and N) of about 200 grams mass were placed in the thermal flux of the Pennsylvania State University reactor. Foils of tantalum and gold, shielded from thermal neutron capture by borated plastic, were placed next to the gamma emitters. After a few hours' exposure, the foils were counted for the $Ta^{180(m)}$ 8.15-hr x ray or the $Au^{196}$ 5.6-day x ray by scintillation methods. By using the energies and intensities of the neutron-capture gamma rays, which have been measured at other laboratories,[1] thresholds and cross sections at photon energies up to 10.8 Mev were deduced for the reactions studied.

* National Science Foundation Predoctoral Fellow.
[1] For example, Bartholomew and Higgs, Chalk River Rept. AECL-669.

**Q3. Low-Energy Protons Produced in the Deuteron Bombardment of Nuclei.*** ROBERT E. PRICE, E. W. HAMBURGER,† AND B. L. COHEN, *University of Pittsburgh.*—When nuclei are bombarded by 14.8-Mev deuterons, a continuous spectrum of protons is observed corresponding to $Q<-2.2$ Mev. The shape and angular distribution of this continuum were studied for several targets, from Li to Au. From the similarity of the spectra from all elements it is concluded that the continuum is due to breakup of the deuteron. The angular distributions are strongly peaked at $<10°$ for light elements, but for heavy elements the peak broadens and moves to $\sim50°$. The energy spectra show a peak which, for increasing angle, moves to lower energies for the light elements and moves to higher energies for heavy elements. The general features of the process are explained by a semiclassical model, without specifying the detailed mechanism for the breakup.

* Work done in the Radiation Laboratory and assisted by the National Science Foundation and by the joint program of the Office of Naval Research and by the U. S. Atomic Energy Commission.
† Now at Departamento de Fisica, Faculdade de Filosofia, Ciencias e Letras, Universidade de Sao Paulo, San Paulo, Brazil.

**Q4. Determination of the Magnetic Structure of the Neutron.*** H. W. KENDALL, J. I. FRIEDMAN, AND P. GRAM, *Stanford University.*—Elastic electron-scattering experiments from deuterium, at constant four-momentum transfer $q$, yield information on the magnetic moment structure of the deuteron. This information can be related, by the impulse approximation and the experimental result[1] that $F_{1p}\cong F_{2p}$, to the magnetic structure of the neutron, assuming $F_{1n}=0$. Measurements have been completed for $q$ in the range from 1.0 to 2.8 fermi$^{-1}$. The magnetic form factor of the neutron is, within the experimental error, the same as that of the proton's anomalous magnetic moment for $q$ from 1.6 to 2.25 fermi$^{-1}$. The average of the ratio of form factors over the measured interval is $(0.905\pm0.08)$. Measurements of the transition form factor for the electron disintegration of the deuteron near threshold have also been completed. Determination of the deuteron's charge structure are in agreement with earlier work.

* Supported in part by the joint program of the office of Naval Research, the U. S. Atomic Energy Commission, and the U. S. Air Force Office of Scientific Research.
[1] R. Hofstadter, F. Bumiller, and M. R. Yearian, Revs. Modern Phys. 30, 482 (1958).

**Q5. Electron-Scattering Investigation of the Anomalous Levels in Lead, Bismuth, Nickel, and Cobalt.*** H. CRANNELL, R. HELM, H. W. KENDALL, J. OESER, AND M. YEARIAN, *Stanford University.*—We have measured the form factors for elastic and inelastic scattering of electrons from $Co^{59}$, $Ni^{58}$, $Ni^{60}$, $Pb^{208}$, and $Bi^{209}$. Nuclear excitations up to 6 Mev were

studied; the levels seen by Cohen[1] were observed. The scattering from $Pb^{208}$ and $Bi^{209}$ is qualitatively similar. The form factors of the 4.3-Mev anomalous level scattering differ qualitatively from that of the 2.6-Mev levels, but the results do not exclude $3^-$ assignments[2] for the 4.3 level. Assuming all the states to be $3^-$ we obtain preliminary estimates of $(3.8\pm1.0)\times10^{10}$ sec$^{-1}$ for the ground-state transition rates for the 2.6-Mev levels, and $(0.88\pm0.35)\times10^{12}$ sec$^{-1}$ for the ground-state transition rates for the anomalous levels. The scattered spectra from $Co^{59}$, $Ni^{58}$, and $Ni^{60}$ show strong similarities to one another. In $Ni^{60}$ we obtain preliminary estimates of $(1.5\pm0.7)\times10^{12}$ and $(1.3\pm0.7)\times10^{4}$ sec$^{-1}$ for the $1.33(2^+)$ and $2.50(4^+)$ ground-state transition rates. Taking Crut and Wall's[3] assignment of $3^-$ for the anomalous level at $(4.05\pm0.1)$ Mev in $Ni^{60}$, we obtain $(3.0\pm1.0)\times10^{10}$ sec$^{-1}$ for the ground-state transition rate.

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the U. S. Air Force Office of Scientific Research.
[1] B. L. Cohen and A. G. Rubin, Phys. Rev. 111, 1568 (1958).
[2] A. M. Lane and E. D. Pendlebury (to be published).
[3] M. Crut and N. S. Wall, Phys. Rev. Letters 3, 520 (1959).

**Q6. Inelastic Electron Scattering from Levels of Light Nuclei.*** F. BERTHOLD,† W. C. BARBER, G. FRICKE,‡ AND F. E. GUDDEN,§ *Stanford University.*—We have measured the electron energy spectra resulting from the scattering of 40-Mev primary electrons at angles of 132° and 160° from targets of $Li^6$, Be, and Si. A virtual photon theory[1] is used to relate the areas of inelastic peaks to the integrated cross section for $\gamma$ absorption. For $Li^6$, peaks corresponding to excitation of the states at 2.18 and 3.56 Mev were observed. The 3.56-Mev peak showed an angular dependence within 4% of that predicted theoretically for an $M$-1 transition. The 2.18-Mev peak has a different angular dependence which is within experimental error of that predicted for an $E$-2 transition. By using these assignments for the transitions, we calculate the integrated cross sections to be $(6.0\pm0.3)\times10^{-28}$ and $(8\pm4)\times10^{-31}$ Mev-cm$^2$ for the 3.56- and 2.18-Mev levels, respectively. The corresponding radiation widths are 5.9 and $4.1\times10^{-4}$ ev. Several levels are observed in Be. Si shows a prominent one at 11.6 Mev.

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the U. S. Air Force Office of Scientific Research.
† On leave from Max-Planck-Institut, Mainz (introduced by W. C. Barber).
‡ On leave from Institut für Technische Kernphysik, Darmstadt (introduced by W. C. Barber).
§ Present address: Institut für Technische Kernphysik, Darmstadt.
[1] R. H. Dalitz and D. R. Yennie, Phys. Rev. 105, 1598 (1957).

**Q7. Inelastic Electron Scattering from the Giant Resonance Region of Nuclei.*** W. C. BARBER, F. BERTHOLD, G. FRICKE, AND F. E. GUDDEN, *Stanford University.*—We have observed peaks in the energy spectra of electrons scattered at 160° from targets of C, Si, and Pb at excitation energies of 23, 20, and 15 Mev from the targets, respectively. The excitation energies and peak widths are consistent with the giant resonances for these nuclei. The areas of the inelastic peaks are related to the integrated cross sections for $\gamma$ absorption through the theory of virtual photons. A previous result[1] that this analysis gave a too small cross section for the $C$ resonance is at least partly corrected by recent measurements indicating a decrease of detector efficiency with decreasing electron energy. When the data are corrected for this dependence, the resulting integrated cross sections are: C, 80 Mev-mb; Si, 120 Mev-mb; Pb, 6000 Mev-mb. The results are uncertain by a factor of approximately 2 because they depend on arbitrary assumptions about nuclear form factors and arbitrary methods used in subtracting the continuum of low-energy electrons. We hope to alleviate this second difficulty by measuring at larger scattering angles.

* Supported by the joint program of the Office of Naval Research, the U. S. Atomic Energy Commission, and the U. S. Air Force Office of Scientific Research.
[1] W. C. Barber and F. E. Gudden, Phys. Rev. Letters 3, 219 (1959).

**Q8. Comparison of Cluster-Model Predictions with Experimental Nuclear Levels.*** R. K. SHELINE AND K. WILDERMUTH, *Florida State University.*—Nuclei may be considered to be composed of clusters ($He^4$, $He^3$, $H^3$, and free nucleons) similar in many respects to molecules in molecular physics. This cluster model predicts low-lying energy levels of *parity different than the ground state* (i.e., levels in higher shells) for nuclei in which there is a free neutron or proton incapable or further completing other clusters in this nucleus. The corresponding levels in nuclei containing *di*-neutrons, *di*-protons of deuterons as smallest clusters should be slightly higher. The greater stability of $H^3$, $He^3$, and $He^4$ cluster nuclei suggests still higher corresponding levels. This model further predicts that immediately after double closed-shell structures, nuclei with $H^3$ or $He^3$ clusters (e.g., $F^{19}$) will exhibit a strong decrease in this excitation energy. The negative parity states and first 0+ states in alphpa-article nuclei should decrease with increasing atomic number. These predicted systematics agree with the limited experimental data which are available but suggest the need for considerable additional data to further test the predictions. These results indicate substructures which are often more important than shell-model structures.

* This and the next three papers placed in an experimental-physics session at the authors' request.

**Q9. Reduced α-Particle Widths, Gamma-Transition Probabilities, in the Light of the Cluster Model.** B. ROTH† AND K. WILDERMUTH, *Florida State University.*—On the basis of the cluster model[1] one expects large reduced $\alpha$-particle widths for those excited states of a nucleus which can be described as an $\alpha$-particle cluster bound to an unexcited cluster, and where no $\alpha$-particle cluster is broken up. When the $\alpha$-particle cluster is broken up or when the $\alpha$ particle is bound to an excited cluster, there should be a small reduced width for that state. One also expects the relative magnitude (in Weisskopf units) of the gamma-transition matrix element to be large when the states involved have a similar cluster structure, and to be small when they are dissimilar in cluster structure. From this point of view, the gamma radiation of the low-lying states of $F^{19}$ and $O^{16}$, and the reduced $\alpha$-particle widths of $O^{16}$ were analyzed. Good agreement with experiment was found in all cases where data are available.

* On leave from Oklahoma State University.
[1] K. Wildermuth and Th. Kanellopoulos, Nuclear Phys. 7, 159 (1958); 9, 449 (1958/59); CERN Rept. 59-23 (1959).

**Q10. Low-Lying Levels of Light Nuclei in the Cluster Model.*** L. D. PEARLSTEIN, Y. C. TANG, AND K. WILDERMUTH, *Florida State University.*—The low-lying energy levels of light nuclei with $A=6$, 7, 8 are computed by the Ritz variational method. The trial wave functions are chosen to exhibit the feature of relatively long-range correlations as clustering of nucleons in those various nuclei.[1] For instance, in the case of $Li^7$, the wave function is written as the antisymmetrized product of a part which represents the internal structures of an $\alpha$-particle cluster and a triton cluster and a part which describes the relative motion between the two clusters. To facilitate computations, it is assumed that the interaction energy between the clusters is little influenced by the hard-core part of the nuclear two-body force; hence, it can be approximately calculated by a Serber force of nonsaturating character. For the internal energies of the clusters, values computed by Mang and Wild[2] using saturated force with hard

core are adopted. Numerical results indicate that our computations yield good agreement with both the ground-state energies and the energies of the first few excited states of those nuclei considered.

* Partially supported by the U. S. Air Force Office of Scientific Research.
[1] K. Wildermuth and T. Kanellopoulos, Nuclear Phys. **7**, 150 (1958); **9**, 449 (1958/59); also CERN Rept. 59-23.
[2] H. J. Mang and W. Wild, Z. Physik **154**, 182 (1959).

**Q11. Asymmetric and Symmetric Fission and the Cluster Model.*** K. WILDERMUTH, *Florida State University*, AND H. FAISSNER, *CERN*.—It is suggested that asymmetric fission involves two essentially unexcited clusters with $N=50$ and $N=82$, respectively. These energetically favored nuclear cluster structures can exist in a nucleus without destroying the 126 shell of neutrons because of the indistinguishability of the nucleons. In symmetric fission, however, these substructures have disappeared. It will be shown that all experimental facts of fission agree with this concept. In particular, (1) the triple peaked mass distributions observed present evidence that the familiar change from asymmetric to symmetric fission with increasing excitation energy means the appearance of a new distinct fission mode, rather than simply filling up the valley; (2) the excitation energies of fragments measured so far show a minimum at the most probable (asymmetric) mass division, rather than a maximum; (3) the very existence of the angular anisotropies observed implies that only a few fission channels are open, contrary to any statistical description.

* K. Wildermuth and Th. Kanellopoulos, Nuclear Phys. **7**, 150 (1958); **9**, 449 (1958/59); CERN Rept. 59-23 (1959).

**Q12. Nonelastic Scattering of Neutrons from Metastable Nuclei.** JAMES B. WEDDELL, *The Martin Company*.—An experiment is proposed in which medium fast neutrons are to be scattered by a nuclear isomer which is in a long-lived metastable state several kev above the ground state. Measurement of the energy distribution of the scattered neutrons should provide information on the importance of surface interactions with single neutrons versus compound nucleus interactions. If the metastable state is the result of the excitation of a single nucleon, some scattered neutrons should have energy $(E_0+E_m)$, where $E_0$ is the incident neutron energy and $E_m$ is the energy of the metastable state. If the excess energy of the metastable state is shared statistically among all the nucleons, few or no scattered neutrons will have energy greater than $E_0$. If the scattered neutron energy distribution in the latter case conforms to the evaporation model, the nuclear temperature is expected to be $T=T_0(E_0+E_m)^{\frac{1}{2}}$, where $T_0$ is the temperature characteristic of incident neutron energy $E_0$.[1] The choice and means of production of the isomer will be discussed.

[1] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, Inc., New York, 1952).

### *Invited Paper*

**Q13. A Two-Body Cluster Model of the Nucleus.** G. C. PHILLIPS, *Rice Institute*. (30 min.)

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## WEDNESDAY MORNING AT 9:45

Sheraton Hall

(R. V. POUND presiding)

### *Invited Papers*

**QA1. Experimental Tests of the General Theory of Relativity.** L. I. SCHIFF, *Stanford University*. (30 min.)

**QA2. Nuclear Resonant Absorption of Recoil-Free Gamma Rays.** R. L. MOSSBAUER, *Technische Hochschule Muenchen*. (30 min.)

**QA3. Invisibility of the Lorentz Contraction.** JAMES TERRELL, *Los Alamos Scientific Laboratory*. (30 min.)

**QA4. Critique of Theories of Irreversibility.** R. ZWANZIG, *National Bureau of Standards*. (30 min.)

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## WEDNESDAY MORNING AT 10:00

Adams-Hamilton Room

(D. E. MANN presiding)

### *Hyperfine Structure and Allied Topics*

**R1. Microwave Zeeman Spectrum of Atomic Fluorine.*** H. E. RADFORD, V. W. HUGHES, AND V. BELTRAN-LOPEZ, *Yale University*.—The microwave Zeeman spectrum of $F^{19}$ in its $^2P_{\frac{1}{2}}$ ground level has been measured to a precision of 1 ppm by the method of paramagnetic resonance absorption in an atomic vapor.[1] The intermediate field character of the spectrum when observed at 3-cm wavelength permits an accurate determination of both the atomic $g$ factor and the magnetic dipole hfs constants. A detailed analysis, in which both magnetic and hyperfine perturbations by the neighboring $^2P_{\frac{1}{2}}$ level were considered, yields $-g_J(F;^2P_{\frac{1}{2}})/g_P=438.4839+0.0003$, $\Delta W(F;^2P_{\frac{1}{2}})/h=4020.01\pm0.02$ Mc/sec, and $-a'''(F;^2P)/h=446\pm10$ Mc/sec, where $g_P$ is the $g$ factor of protons in a cylindrical sample of mineral oil. The quantity $a'''$ is the coupling constant of the off-diagonal (in $J$) hfs interaction in the $^2P$ term. The value of the experimental ratio $\Delta W/a'''$

indicates a strong perturbation of the fluorine hfs, of the sort that would be produced by an isotropic ($s$-electron) hfs coupling of 149 Mc/sec. On combining the measured $g$-factor ratio with the result of similar experiments on atomic hydrogen, one finds $g_J(F;\,^2P_{\frac{1}{2}})/g_J(H;\,^2S_{\frac{1}{2}})=\frac{2}{3}-(497\pm2)\times10^{-6}$. The theoretical significance of this ratio will be discussed in a later, detailed account of this work.

* This work was supported in part by the Office of Naval Research.
[1] H. E. Radford, Bull. Am. Phys. Soc. Ser. II, 3, 325 (1958).

**R2. Microwave Zeeman Spectrum of Atomic Chlorine.*** V. BELTRAN-LOPEZ AND H. G. ROBINSON, *Yale University.*—Five transitions, $\Delta M_J=\pm1$, $\Delta M_I=0$, in the Zeeman spectrum of $Cl^{35}$ in its $^2P_{\frac{1}{2}}$ ground state have been measured at $\simeq$9190 Mc/sec. The magnetic dipole and electric quadrupole hyperfine interactions were treated as perturbations through third order on the Zeeman splitting of the $^2P_{\frac{1}{2}}$ state. The hyperfine constants used were those obtained from atomic beam measurements.[1] Finally, without inclusion of hyperfine effects, the interaction with the $^2P_{\frac{1}{2}}$ state was approximated by a perturbation calculation accounting for the mixing of the two states by the magnetic field. Thus a $g_J$ was computed for each of the observed transitions. Averaging all $g_J$, we find $\bar{g}_J=1.333916\pm0.000015$.[2] The quoted error is three times the maximum deviation ($\pm0.000005$) of the $g_J$ from the average $g_J$. This deviation, in turn, is large compared to the experimental statistical error of a $g_J$ for any given transition. The spread in $g_J$ is believed to result from the approximate treatment used to describe the $^2P_{\frac{1}{2}}$ state interaction with the ground state. Because a detailed calculation of this interaction is not yet completed, we have quoted the error in $\bar{g}_J$ to include reasonable possible corrections.

* This work was supported in part by the Office of Naval Research.
[1] J. H. Holloway, B. B. Aubrey, and J. G. King, MIT Quarterly Progr. Rept. R.L.E. April 15, 1956, p. 55.
[2] Compare G. Wolga and M. W. P. Strandberg, Bull. Am. Phys. Soc. Ser. II, 4, 153 (1959); $g_J=1.33376\pm0.00007$.

**R3. Nuclear Moments of $I^{133}$.*** S. S. ALPERT, E. LIPWORTH, AND M. B. WHITE, *Lawrence Radiation Laboratory, Berkeley.*—The magnetic dipole interaction constant '$a$' and the electric quadrupole interaction constant '$b$' of 21-hr $I^{133}$ have been measured by a "flop-in" atomic-beam magnetic resonance experiment. The spin of $I^{133}$ is known to be 7/2.[1] The results are $a=596.8\pm1.0$ Mc/sec and $b=385.8\pm7.4$ Mc/sec. By using these results and the known magnetic dipole moment of $I^{127}$, the magnetic dipole moment (uncorrected for diamagnetism) and the electric quadrupole moment (corrected for core polarization) of $I^{133}$ were calculated to be $|\mu_{133}|=2.821\pm0.005$ nm and $|Q_{133}|=0.27\pm0.01$ b, respectively. The electric and magnetic moments must have opposite signs; the sign of $\mu_{133}$ is very probably positive. The active sample was obtained as a fission product from the Brookhaven National Laboratory. A total of 14 resonances were observed in fields ranging from 26 gauss to 300 gauss, the observed transitions being ($F=5$, $m_f=-3\rightarrow F=5$, $m_f=-4$) and ($F=4$, $m_f=-2\rightarrow F=4$, $m_f=-3$). The data was reduced using an IBM 704 digital computer.

* This work was supported by the U. S. Atomic Energy Commission.
[1] H. L. Garvin and E. Lipworth (to be published).

**R4. Hyperfine Structure Anomaly of $Cs^{140m}$.*** VICTOR W. COHEN AND JACK SCHWARTZ, *Brookhaven National Laboratory.*—It is possible to measure the nuclear gyromagnetic ratio for an atom in a $^2S_{\frac{1}{2}}$ state by performing an atomic-beam resonance "flop-in" experiment. The frequency separation between the two transitions,

$$F(I+J),\quad m_F[-(I+J-1)]\leftrightarrow F(I-J),\quad m_F[-(I-J-1)]$$

and

$$F(I+J),\quad m_F[-(I+J-2)]\leftrightarrow F(I-J),\quad m_F[-(I-J)],$$

can be calculated from the Breit-Rabi formula and is $2g_i\mu_0H/h$. In the intermediate field region these transitions show a frequency minimum. Under such conditions the lines can be made extremely narrow and high precision in the splitting can be observed. In $Cs^{134m}$ (3.1 hr) the transitions occur at approximately 2065 $\mu$c/sec. Using the separated rf loop technique we have observed this doublet splitting with a preliminary value of about 218 kc with an estimated error of not greater than 7 kc. This yields a value of $g_i=0.712\times10^{-6}$ and a hfs anomaly with respect to $Cs^{133}$ of about 0.06 with an estimated error of not over 0.03. This would appear to be considerably higher than any other hfs anomaly so far observed. Further work is being done to improve the accuracy.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**R5. Nuclear Spin and Hyperfine Structure of $Tm^{170}$.*** INGVAR LINDGREN, AMADO CABEZAS, AND WILLIAM NIERENBERG, *Lawrence Radiation Laboratory, Berkeley.*—The nuclear spin and hfs of $Tm^{170}$ (129 days) have been measured with the atomic-beam magnetic resonance method, using "flop-in" technique and radioactive detection. The isotope was produced by the reaction $Tm^{169}(n,\gamma)Tm^{170}$. Four flop-in transitions have been observed at several different magnetic fields with the following results:

$$I=1,\quad g_J=1.1412\pm0.0002,$$
$$|a|=200\pm4\text{ Mc/s}\quad\text{and}\quad|b|=1010\pm20\text{ Mc/s}.$$

From the magnetic dipole and electric quadrupole interaction constants the following approximate values of the moments have been calculated:

$|\mu|=0.25$ nm and $|Q|=0.6$ b with $\mu$ and $Q$ of the same sign.

The atomic $g$ value deviates significantly from the Landé value, 1.1428. This discrepancy is caused mainly by relativistic and diamagnetic effects.

* This work was supported by the U. S. Atomic Energy Commission, the Office of Naval Research, and the Swedish Atomic Energy Commission.

**R6. Nuclear Spin of $Lu^{176m}$.*** M. B. WHITE, S. S. ALPERT, AND E. LIPWORTH, *Lawrence Radiation Laboratory, Berkeley.*—The nuclear spin of 3.7 hour $Lu^{176m}$ has been measured by an atomic-beam magnetic resonance flop-in experiment using radioactive detection. Observations were made using $Lu^{176m}$ atoms in the $^2D_{5/2}$ atomic ground states. The value $I=1$ was measured by observing transitions in the states $F=\frac{7}{2}$ and $F=\frac{5}{2}$ at three different values of the applied magnetic field. The $Lu^{176m}$ was prepared by the $Lu^{175}(n,\gamma)Lu^{176m}$ reaction using the pool-type reactor at the University of California Lawrence Radiation Laboratory in Livermore, California. Metallic $Lu^{175}$ was irradiated in approximately 80-mg lots for about 3 hr at a flux of about $2\times10^{13}$ neutrons/cm$^2$/sec. $Lu^{176m}$ atoms passing through the atomic-beam apparatus were collected on flamed platinum foils and detected by counting the decay $\beta$ particle in continuous flow methane beta counters.

* This work was supported by the U. S. Atomic Energy Commission.

**R7. Nuclear Spin of Lutetium-177.*** F. R. PETERSEN AND H. A. SHUGART, *University of California and Lawrence Radiation Laboratory, Berkeley.*—The nuclear spin $I=7/2$ for radioactive lutetium-177 ($T_{\frac{1}{2}}=7$ days) has been measured in the electronic state $^2D_{5/2}$ by the atomic-beam magnetic resonance method. The low-frequency "flop-in" resonances which were observed correspond to the transitions $F$, $m_F=6$, $-3\leftrightarrow6$, $-4$ and $F$, $m_F=5$, $-2\leftrightarrow5$, $-3$. Nine such resonances have been observed at fields from 24 to 210 gauss. The quadratic and higher ordered shifts observed in these resonances have yielded preliminary values for the interaction constants $a$ and $b$. The radioactive isotope was produced from the stable metal

by the reaction $Lu^{176}(n,\gamma)Lu^{177}$ in the Livermore pool-type reactor. Purity of the radioactive isotope was established from pulse-height analysis of the gamma-ray spectrum. Resonance detection was accomplished by collecting the radioactive atoms on sulfur-coated "buttons" which were later counted in continuous flow beta-counters.

* Supported in part by the U. S. Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.

**R8. Hyperfine Structure of $Hg^{199}$: An Application of the Level-Crossing Technique.*** H. R. HIRSCH, *Massachusetts Institute of Technology.*—The level-crossing technique of Colgrove, Franken, Lewis, and Sands[1] has been applied to the hyperfine structure of $Hg^{199}$. Light of 2537 A which is scattered at right angles decreases sharply at a field of 7095 gauss. This value leads to a magnetic dipole interaction constant, $A$, of 14 743±15 Mc. The limit of error depends upon knowledge of the electronic $g$ factor and of the field. The result of the present work is to be compared with the $A$ value that C. Stager[2] obtained by a direct rf resonance: 14 752.37±0.02 Mc.

* Work partially supported by U. S. Army (Signal Corps), U. S. Air Force (Office of Scientific Research, ARDC) and U. S. Navy (ONR).
[1] F. D. Colgrove, P. A. Franken, R. R. Lewis, and R. H. Sands, Phys. Rev. Letters 3, 420 (1959).
[2] C. Stager and R. Kohler, Bull. Am. Phys. Soc. Ser. II, 5, 274 (1960).

**R9. Measurement of the Atomic $g$ Values of $Hg^{203}$, $Hg^{199}$, and $Hg^{201}$ in the $6^3P_2$ State.*** BERTRAND B. AUBREY† AND LEE C. BRADLEY, III, *Massachusetts Institute of Technology.*—Hg atoms were excited to the metastable $6^3P_2$ state by unidirectional electrons in a planar diode containing Hg vapor at low pressure. The slignment was monitored by the absorption of polarized λ5461 radiation from an $Hg^{198}$ lamp in a "scanning" magnetic field, which permitted the selection of a particular hfs component to be studied. Transitions between the Zeeman sublevels of the $^3P_2$ state were induced by a radiofrequency field (50 Mc/sec) of a few milligauss. Resonances were obtained in the even isotopes, the $F=\frac{5}{2}$ and $F=\frac{3}{2}$ levels of $Hg^{199}$, and the $F=\frac{7}{2}$ and $F=\frac{5}{2}$ levels of $Hg^{201}$. The $g$ values for the resonances are:

| | | |
|---|---|---|
| Even isotopes: | $g_J=1.5007$ | ± (4) |
| $Hg^{199}$: $F=5/2$; | $g_F=1.1997$ | ± (5) |
| $F=3/2$; | $g_F=1.7993$ | ±(11) |
| $Hg^{201}$: $F=7/2$; | $g_F=0.85706$ | ±(80) |
| $F=5/2$; | $g_F=0.9424$ | ±(12) |

The line widths in all cases were a few hundred kilocycles and are believed to be mainly due to magnetic field inhomogeneity.

* This work was supported in part by the U. S. Army Signal Corps, the U. S. Air Force Office of Scientific Research, Air Research and Development Command, and the Office of Naval Research.
† Now at Yale University.

**R10. Hyperfine Structure of $Hg^{199}$ and $Hg^{201}$ in the $^3P_1$ State.*** C. STAGER AND R. KOHLER, *Massachusetts Institute of Technology.*—We have measured the hyperfine structure splittings of the $^3P_1$ state by paramagnetic resonance using optical detection. The technique used is a modification of the "double-resonance" experiment of Bitter and Brossel[1] in that selective absorption of certain hfs levels, rather than change in polarization, is used to detect the resonance. The results are: $Hg^{199}$: $\Delta\nu=22\,128.56\pm0.02$ Mc; $Hg^{201}$ ($H=\frac{5}{8}$ to $\frac{1}{2}$): 13986.557 ±0.008 Mc; ($F=\frac{5}{2}$ to $\frac{3}{2}$) 7551.613±0.013 Mc. Combining these data with the magnetic moment values,[2] we calculate the Bohr-Weisskopf effect.[3] We find $\Delta(^3P_1)=-0.1637(23)\%$, as compared with $\Delta(^3P_2)=-0.1728(12)\%$ (McDermott[4]), and $\Delta$ (Knight shift) $=-0.16(10)\%$ (Eisinger *et al.*[5]). Our value of $\Delta$ does not include electronic corrections.

* Work partially supported by U. S. Army (Signal Corps), U. S. Air Force (Office of Scientific Research, ARDC), and U. S. Navy (Office of Naval Research).
[1] J. Brossel and F. Bitter, Phys. Rev. 86, 308 (1952).
[2] B. Congnac and J. Brossel, Compt. rend. 249, 77 (1959).
[3] A. Bohr and V. Weisskopf, Phys. Rev. 77, 94 (1950).
[4] M. McDermott (private communication to H. Stroke).
[5] J. Eisinger, W. E. Blumberg, and R. G. Shulman, Bull. Am. Phys. Soc. Ser. II, 4, 451 (1959).

**R11. Hyperfine Structure of $Am^{241}$.*** R. MARRUS, W. A. NIERENBERG, AND J. WINOCUR, *Lawrence Radiation Laboratory, Berkeley.*—The atomic-beam magnetic resonance method has been used to determine the hyperfine structure of $Am^{241}$. The electronic and hyperfine-structure constants of the electronic ground state are found to be $J=\frac{7}{2}$, $g_J=1.937$ ±0.001, $A=\pm17.144\pm0.008$ Mc, and $B=\mp123.817\pm0.097$ Mc. In addition, a previous measurement[1] of $I=\frac{5}{2}$ for the nuclear spin has been verified. The observed values indicate the ground-state configuration is almost certainly $(5f)^7(7s)^2$. The departure of the measured values from those obtained for a pure Hund's Rule ground state of $^8S_{7/2}$ will be discussed from the point of view of the breakdown of $L$-$S$ coupling. Effects of configuration interaction will also be discussed.

* This work performed under the auspices of the U. S. Atomic Energy Commission.
[1] F. S. Tompkins and M. Fred, J. Opt. Soc. Am. 39, 357 (1949).

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## WEDNESDAY MORNING AT 9:30

Burgundy Room

(M. A. POMERANTZ presiding)

### *Invited Papers in Space Physics*

**RA1. Physics of the Moon.** ROBERT JASTROW, *N.A.S.A.* (30 min.)

**RA2. Theory and Observation of Geomagnetically Trapped Radiation.** S. F. SINGER, *University of Maryland.* (30 min.)

**RA3. X-Ray Emission Accompanying Solar Flares.** T. A. CHUBB, *Naval Research Laboratory.* (30 min.)

**RA4. Use of Doppler Frequency Measurements in Space Research.** R. R. NEWTON, *Applied Physics Laboratory, Johns Hopkins University.* (30 min.)

WEDNESDAY MORNING AT 10:00

Franklin Room

(P. W. ANDERSON presiding)

## *Theoretical Physics V: Many-Body Problems*

**S1. Interaction of Electromagnetic Radiation with an Electron Gas.*** NARKIS TZOAR AND ABRAHAM KLEIN, *University of Pennsylvania.*—We have studied the absorption and inelastic scattering of photons by an electron gas. It is shown that to the lowest order in the electromagnetic field the knowledge of the two-particle Green's function determines the above cross sections. The required propagator has been calculated in the high-density approximation, and formal results for the cross sections given, which are exact for any order of $r_s$ in the high-density limit. The cross sections have been computed to the lowest order in $r_s$. It is found that the class of diagrams which normally contributes to the so-called "random phase approximation" does not contribute at all to the absorption process. Rather only the exchange diagrams contribute in the dense gas approximation. The exact cross section for the inelastic scattering is given formally for the above approximation. In particular, it is possible to calculate the corrections to the result that one gets from the assumption of the "random phase approximation," which, contrary to the absorption case, gives an important contribution to the process in question.

* Supported in part by the U. S. Atomic Energy Commission.

**S2. Collective Coordinates in a Positive Density. Phase Space for the Many-Body Problem.** GEORGE J. YEVICK, *Stevens Institute of Technology,* AND JEROME K. PERCUS, *New York University.*—In previous work, we have stressed the importance of momenta for the description of high-wave-number collective coordinates required for the onset of thermal motion or chaos. The difficulty in ordinary quantum mechanics is that the momentum is not amenable to manipulation due to its being an operator in a $q$ representation. However, if we use the phase-space approach to quantum mechanics, the momentum becomes a $c$ number on the same footing as the coordinate. This suggests the use of collective coordinates in phase space which mix the coordinates and momenta in an intimate manner. An example of this is the Bohm-Pines collective coordinate. If we extend the equations of motion for a positive density in phase space first derived by Bopp to the many-body problem and drop all terms containing powers higher than $\hbar^2$, we obtain an approximate equation which reduces correctly to the classical limit unlike the usual quantum mechanics. By utilizing the methods of Bogoliubov and Zubarev, the equations of motion in phase space can be transposed to the more general equations in collective coordinate space. Methods for diagonalization will be discussed.

**S3. Two-Body Reduction of the *N*-Body Problem.** J. K. PERCUS, *New York University,* AND G. J. YEVICK, *Stevens Institute of Technology.*—It is well known that most properties of interest for many-body systems are consequences of the two-body distribution function. In particular, for the case of two-body forces, the energy is expressible in these terms. This suggests a variational method for the quantum mechanical energy as a functional of the two-body density matrix, with the apparent advantage of reducing the problem to one of just two particles. However, not all two-body densities are possible, even kinematically; some necessary restrictions have been discussed by Watanabe, Mayer, Tredgold, and Ayres. Under certain conditions, the adequacy of such a two-body density may be guaranteed by constructing it from a legitimate $N$-body distribution. On the other hand, for heuristic purposes, one may pose the simpler problem of determining all conditions to be satisfied by a two-body configurational probability function which belongs to an $N$-body system. This problem has been solved in principle, and the corresponding general form for the two-body probability obtained. Extension to the two-body density matrix required for quantum mechanics is then immediate. A number of practical procedures are suggested and their utility will be discussed.

**S4. Generalized Entropy Principle for Nonequilibrium Processes.** J. L. LEBOWITZ,* *Yeshiva University,* AND E. HELFAND AND H. L. FRISCH, *Bell Telephone Laboratories.*—It was shown by Gibbs that the canonical distribution maximizes the entropy of a system represented by a $\Gamma$-space ensemble. He also showed separately that this distribution is a stationary solution of the dynamical problem, i.e., the Liouville equation. This permitted Gibbs to identify the canonical ensemble with equilibrium systems which identification has proven capable of predicting all the properties of equilibrium systems. We believe that we have found a generalization of this principle which holds also for systems that are slightly out of equilibrium (linear transport processes). The quantity $R$ whose maximization yield the desired distribution is the sum of the system's entropy and the entropy produced by the transport processes during the past history of the system. This entropy production is related to the change in entropy of the heat baths with which the system is in contact. $R$ thus may be considered as the entropy of the system plus its surroundings with respect to a suitably chosen reference level.

* Supported by the U. S. Air Force Office of Scientific Research.

**S5. Local Equilibrium Distribution Functions.** H. L. FRISCH, *Bell Telephone Laboratory,* AND J. L. LEBOWITZ,* *Yeshiva University.*—The form of the radial distribution function $g$ in a system with nonuniform temperature, represented by a local equilibrium ensemble, is investigated. For an open system, represented by a grand ensemble, $g(r_{12})$ is qual to its value in an equilibrium system at the temperature and density of the midpoint between the molecules one and two to terms linear in the gradients. For a system with a fixed number of particles the requirement that $g$ be an intensive quantity leads to a relation between the asymptotic values of the three-particle and four-particle equilibrium distributions. This relation is explicitly shown to be satisfied to first-order terms in the density. Some other results about these asymptotic values are also established.

* Supported by the U. S. Air Force Office of Scientific Research.

**S6. Some Remarks on the Ground-State Energy of the Hard Sphere Bose Gas.** ELLIOTT LIEV, *Cornell University.*—The ground-state energy of a gas of hard spheres of radius $a$ is well known to be of the form $E=N\rho^{\frac{1}{3}}f(x)$, where $x=\rho a^3$. While $f(x)$ changes in a relatively well-behaved way from low to critical density, it has proved impossible to evaluate it even approximately over the entire range of density owing to the fact that the wave function changes drastically. Therefore an attempt has been made to discuss $f(x)$ without calculating wave functions. The method used has been to write a differential equation for $f(x)$ by noticing that it is related to its deriva-

tive through the virial theorem. A further unknown function $m(x)$ is introduced which is essentially the decrease in volume which gives the same increase in the virial as the introduction of one more particle to the box. One can then make "educated guesses" about $m(x)$ and hence about $f(x)$. Alternatively, a lower bound for $m(x)$, which is relatively easy to find, gives a lower bound for $f(x)$ over the entire range $x$.

**S7. Energy Transfer between Modified Maxwell Distributions.*** HOWARD D. GREYBER,† *Lawrence Radiation Laboratory, Livermore.*—A particularly convenient form of modified Maxwell distribution is chosen. The expressions for (a) the energy transfer from ions to electrons in a plasma, and (b) the bremsstrahlung from the electrons, with a modified Maxwell distribution for both ions and electrons or only for the ions, are derived. By using the expressions derived, some possible steady-state conditions for the ion and electron gases are calculated and compared with those conditions with the usual Maxwell distributions assumed for both gases. The modified Maxwell distribution chosen is similar to what one might expect for the plasma in a magnetic mirror machine with appreciable end losses.

* Supported by the U. S. Atomic Energy Commission.
† Now at Geophysics Corporation of America.

**S8. Approximations in the Theory of Dense Fluids.** F. H. STILLINGER, JR., *Bell Telephone Laboratories.*—A fluid of rigid spheres in equilibrium is considered from a viewpoint which allows the equation of state to reflect very sensitively the accuracy of two approximations to the triplet distribution function. Specifically, these approximations are (1) the usual Kirkwood superposition approximation, and (2) an assumption that the correlation of excess particles near a fixed particle pair is additively composed of the excess induced by each member of the pair (linear correlation field hypothesis). Granted only these hypotheses, each in turn, the rigorous statistical mechanical relations between the rigid sphere distribution functions and the thermodynamic pressure and compressibility, lead unambiguously to nonlinear, first-order differential equations for the pressure as a function of density. The simply obtained numerical solutions clearly demonstrate that assumption (1) is considerably superior to (2).

**S9. Scaled Particle Theory of Fluids.** E. HELFAND, H. REISS, AND H. L. FRISCH, *Bell Telephone Laboratories,* AND J. L. LEBOWITZ,* *Yeshiva University.*—A statistical thermodynamic theory has been developed by employing distance scaling as a coupling procedure. This is an extension to real fluids of the techniques applied by Reiss, Frisch, and Lebowitz[1] to rigid sphere systems. One considers molecules interacting with pair potential $u(r)$, except for one particle which interacts with potential $u(r/\lambda)$. This single particle, essentially a scaled verison of the normal molecules, is termed a $\lambda$-cule. It is convenient to restrict discussion to potentials with rigid cores at $r=a$ and cutoffs at $\gamma a$. Attention is focused on a new function $\Theta(\lambda,\rho,T)$ which reduces to $G$ of Reiss *et al.*[1] in the case of rigid spheres. The pressure, chemical potential, and work of expanding a $\lambda$-cule are simply related to $\Theta$. One can write $\Theta$ exactly for $\lambda<\frac{1}{2}\gamma$, and simple connection conditions hold at $\lambda=\frac{1}{2}\gamma$. An integral condition and $\lambda=\infty$ conditions on $\Theta$ also exist, so that, while $\Theta$ is not completely specified, one knows quite a bit about it. Applications of this formalism will be discussed.

* Supported by the U. S. Air Force Office of Scientific Research.
[1] H. Reiss, H. L. Frisch, and J. L. Lebowitz, J. Chem. Phys. 31, 369 (1959).

**S10. Phonon Character of Quasi-Particle Excitations in the Condensed Bose Systems.*** VIRGINIA F. WALTERS† AND P. R. ZILSEL, *Western Reserve University.*—Bogoliubov's quasi-particle excitations for a Bose system[1] generally[2] have been identified with "phonons," but their relation to quantized density fluctuations[3] has been directly exhibited. The well-known difficulty of defining action-angle variables for a quantum oscillator complicates the construction of operators $S_k$ canonically conjugate to the exact density fluctuation operators $\rho_k$. However, in the limit $V\to\infty$ ($V$=volume of the system), for states close to the ground state (Bose condensation), the dominant part of the $\rho_k$ is $\rho_k{}^0=V^{-\frac{1}{2}}(a_0{}^\dagger a_k+a_{-k}{}^\dagger a_0)$, corresponding to Bogoliubov's approximation. One can construct $S_k{}^0$ conjugate to the $\rho_k{}^0$. In these variables the part of the Hamiltonian diagonalized by the Bogoliubov transformation takes the form $H_0=\Sigma[A(k)\rho_k{}^{0\dagger}\rho_k{}^0+B(k)S_k{}^{0\dagger}S_k{}^0]$, where $A(k)$, $B(k)$ are donstants, and Bogoliubov's quasi-particle creation (destruction) operators are exactly the raising (lowering) operators for these density-fluctuation oscillators.

* Supported in part by the Office of Ordnance Research, U. S. Army.
† National Science Foundation Predoctoral Fellow (Cooperative).
[1] N. N. Bogoliubov, J. Phys. U.S.S.R. 11, 23 (1947).
[2] cf., e.g., K. A. Brueckner and K. Sawada, Phys. Rev. 106, 1128 (1957).
[3] F. London, *Superfluids, Vol. II* (John Wiley & Sons, New York, 1954); Kronig and Thellung, Physica 18, 749 (1952); R. P. Feynman, Phys. Rev. 94, 262 (1954); Bogoliubov and Zubarev, Soviet Phys.—JETP 1, 83 (1955); and others.

**S11. Iterative Solution for the Matrix Representation of Detection Systems.*** RAYMOND GOLD, *Lowell Technological Institute,* AND NORMAN E. SCOFIELD, *U. S. Naval Radiological Defense Laboratory.*—An iterative method is presented for the inversion of output data determined by that class of detection systems which measure continuous spectra. The distinct advantage of this method lies in the fact that the explicit application of the inverse of the "response" matrix of the detection system is no longer necessary. Proof of convergence to the exact solution for the simple two dimensional and triangular type "response" matrices will be given. The more general case also will be discussed. A comparison of the iteration process with that of the direct inversion also will be presented for a particular detection system—namely, a scintillation spectrometer utilizing a collimated 4-in. diam by 4-in. long NaI(Tl) crystal which is commonly utilized for gamma-ray detection.

* Supported in part by the U. S. Naval Radiological Defense Laboratory

**S12. Nature of Light.** BENJAMIN LIEBOWITZ, *350 Fifth Avenue, New York.*—Schroedinger's wide-angled interference experiment (1920) demonstrated that visible light propagates in the classical pattern over extended wavefronts. About 1936, with T. Loew, I repeated this experiment using minute fluorescent light sources requiring 10 days' exposure to photograph the fringes (unpublished). Such results suggested, as alternative to the photon concept, a postconcentration hypothesis[1] which explains absorption of low-energy radiation by interactions among many electrons that initially are only feebly excited by the incident light waves. Einstein's photoelectric equation then becomes a description of energy surfaces in metals. High-energy radiation must be assumed to propagate *not* in the low-energy Maxwellian pattern but in a *conical* pattern (similar to the betatron light) which, at some definite energy, becomes *cylindrical.* Thus at sufficiently high energies this theory reverts to the "photon" as a "Nadelstrahlung." In principle the postconcentration hypothesis can be tested at low energies by photoelectric experiments analogous to the photographic exposure, i.e., shining light pulses on a particulate cathode. Preparations for such experiments are under way at Bowdoin under grant from National Science Foundation to M. A. Jeppesen.

[1] B. Leibowitz, Phys. Rev. 73, 1274(A) (1948). P. G. Bergmann has since informed me of earlier discussions (unpublished) of such noncorpuscular possibilities.

WEDNESDAY MORNING AT 9:30

Continental Room

(E. C. POLLARD presiding)

***Invited Papers in Biophysics***

**T1. Nature and Size of the Genetic Code.** CYRUS LEVINTHAL, *M.I.T.* (40 min.)
**T2. Interactions of Particles and Nuclei in Bacteria.** R. B. ROBERTS, *Carnegie Institute.* (30 min.)
**T3. Structure and Assembly of the Protein Molecules.** HOWARD DINTZIS, *M.I.T.* (30 min.)
**T4.** Title to be announced. H. M. RANDALL, *University of Michigan.* (30 min.)

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WEDNESDAY MORNING AT 9:30

National Bureau of Standards, East Building

(L. MARTON presiding)

***Solid-State Physics, I***

**TA1. Effect of Deuteron Energy on Irradiation Damage in W.*** D. R. MUSS AND J. R. TOWNSEND, *University of Pittsburgh.*—Cyclotron irradiations of 0.0016-in. diameter W wires previously annealed at 500°C have been carried out at 200°K using deuterons having energies of 13.7, 12.0, and 10.3 Mev. The slope of the resistivity versus integrated deuteron flux curve was measured as a function of flux for these energies up to a total resistivity change of about 50% as measured at 200°K. Even though the resistivity change is not a linear function of flux over this large range, the 10.3-Mev slope was found to be a constant multiple of the 13.7-Mev slope up to a resistivity change of 26%; the ratio $(dR/d)_{10.7}/(dR/d)_{13.7}$ was found to be $1.43\pm0.01$. If one assumes a $1/E$ dependence and corrects for the slight nonuniformity of damage due to deuteron energy loss in the sample, the corresponding theoretical slope value is $1.38\pm0.03$ where the uncertainty arises from deuteron energy uncertainties. Thus in contrast to the results of Pearlstein *et al.* at high proton energies, the rate of production of displacements is very close to the expected $1/E$ dependence. The corresponding experimental ratio for the two energies 12.0 and 13.7 Mev was found to be 1.16 as compared with the corrected $1/E$ ratio of 1.15.

* Work supported by the U. S. Air Force Cambridge Research Center, Air Research and Development Command.

**TA2. Effect of Impurities in Silver on Gamma-Ray Angular Correlation.*** C. GIFFELS AND G. W. HINMAN, *Carnegie Institute of Technology.*—The attenuation of the directional correlation of the 0.172- and 0.247-Mev gamma rays emitted following the decay of $In^{111}$ has been studied in several dilute binary alloys of silver. Each source, containing $\frac{1}{2}$ atomic percent of Cd, In, Sn, Sb, or Ge, was activated by bombarding a sheet of the alloy with 40-Mev $\alpha$ particles in the NASA cyclotron in Cleveland. Because of the cubic structure of the metal, no attenuation is expected in the absence of the impurity, and none was observed with properly annealed silver specimens. The attenuation in the alloys is attributed to quadrupole interaction with the incompletely shielded extra charge on the impurity ion. An approximate theory of the shielding of the excess charge by the conduction electrons has been derived by Langer and Vosko[1] using many-body perturbation theory. Their calculation predicts a much longer range shielding than does a Thomas-Fermi type calculation. Results of the present measurements indicate a long-range shielding.

* Supported in part by the U. S. Atomic Energy Commission.
[1] J. S. Langer and S. H. Vosko, J. Phys. Chem. Solids (to be published).

**TA3. Mechanical Deformation of Thin Single-Crystal Gold Films.** A. CATLIN AND W. P. WALKER, *University of Virginia.*—Single-crystal gold films were grown by vacuum evaporation on heated (375°C) sodium chloride substrates. Completely oriented films with thicknesses between 1000 and 4000 A were obtained, with the plane of the film being the (001) crystallographic plane. The mechanical properties were determined by stressing the films using the "bulge" technique; a small hole being drilled through the substrate with a water jet. The differential pressure applied to the exposed area of the film and the deflection of the film were measured. Both the ultimate strength and the elastic modulus were found to increase above the bulk values as the thickness of the films was reduced. The films were observed to undergo considerable plastic deformation, with optically visible bands of apparent mechanical twinning appearing and growing as stress was increased. This apparent twinning also occurred in films subjected to uniaxial tensile stress in the (110) direction.

**TA4. Current-Induced Marker Motion in Copper Wires.*** A. R. GRONE AND H. B. HUNTINGTON, *Rensselaer Polytechnic Institute.*—Measurements of marker motion in copper have been made from 780°C to 1040°C. The experiments resembled similar experiments with gold,[1] except that microhardness indentations were occasionally used as markers instead of transverse scratches. The effect did not depend on marker shape. Temperature measurements were complicated by changing surface emissivity. The temperature calibration was checked against the sample melting point following each run. Below 970°C markers moved toward the cathode with velocities approximately proportional to the self-diffusion coefficient, as might be expected for mass motion caused by momentum exchange with the current. The equivalent resistivity of the defect constituting the activated complex for diffusion was approximately $10^{-4}$ ohm-cm, somewhat higher than for gold. Actual marker velocities were lower by a factor of four due to the lower diffusivity of copper. Above 970°C the marker velocity decreases rapidly, finally reversing direction near 1010°C. This reversal was first noted qualitatively by Wever.[2]

* Supported by the U. S. Atomic Energy Commission.
[1] H. B. Huntington and A. R. Grone, Bull. Am. Phys. Soc. Ser. II, 4, 172 (1959).
[2] H. Wever, Z. Elektrochem. 60, 1170 (1956).

**TA5. Kirkendall Effect in the Au-Ni System.*** C. J. MEECHAN, *Atomics International.*—Isothermal diffusion stud-

ies have been conducted on Au-Ni couples at 915°C. Relative position changes of tungsten wire markers were measured before and after diffusion. Concentration vs penetration curves have been determined as a function of diffusing time from microhardness measurements, following calibration of microhardness as a function of composition on a series of standard alloys. From these measurements, it is found that the width of the interdiffusion zone on the Au-rich side of the original interface is several times greater than the width of the zone on the Ni-rich side. The marker shift is small but measurable and is in the direction of the Au-rich end of the couple. These studies also seem to indicate that the direction of net vacancy flow may be a function of composition in this system.

* Work supported by the U. S. Atomic Energy Commission.

**TA6. Viscosity of Molten Lithium-6 and Lithium-7** N. T. BAN AND D. J. MONTGOMERY, *Michigan State University.*—A critical test of almost any theory of the viscosity of simple liquids is provided by measurement of the viscosity of separated isotopes of the same metallic element, since the force fields remain almost exactly identical, the mass alone changing. The viscosity of $Li^6$ (99.3%) and of $Li^7$ (99.99%) was measured at temperatures somewhat above the melting point (≈180°C) by observing the damping of free oscillations of a bifilar torsion pendulum with a bob consisting of a lithium-filled sphere suspended in a vacuum furnace. Preliminary results for the viscosity at 235.7°C are the following: $Li^7$, 0.392 cp; $Li^6$, 0.369 cp. The ratio of the two values is 1.063, with a precision estimated to be ±0.021. This value is consistent with the value of 1.080, the square root of the mass ratio of the lithium atoms, predicted on certain of the current theories of liquids. The absolute value for natural lithium obtained by interpolation from the above results (≈0.39 cp) is considerably lower than that found by Andrade and Dobbs[1] at this temperature (≈0.57 cp).

* Supported by the U. S. Atomic Energy Commission.
[1] E. N. C. Andrade and E. R. Dobbs, Proc. Roy. Soc. (London) **A211**, 12 (1952).

**TA7. Conductivity of the Oxides of Iron at High Temperatures.** D. S. TANNHAUSER, *Massachusetts Institute of Technology.*—The conductivity and thermoelectric power of wüstite and magnetite have been measured between 1000 and 1450°C. A thin sheet of Puron iron, with platinum electrodes attached, is oxidized under a suitable oxygen pressure. The sample converts reversibly into the various oxides of iron, the ratio Fe:O and therefore $Fe^{2+}$:$Fe^{3+}$ inside the various oxide phases is controlled by the oxygen pressure. We find that the conductivity of wüstite is practically proportional to the concentration of $Fe^{3+}$ in the lattice, and that of magnetite is proportional to the $Fe^{3+}$ concentration. The thermoelectric power against platinum changes sign near the boundary between the two phases and indicates *p*-type conduction in wüstite and *n*-type conduction in magnetite. The conductivity of the two phases is almost the same on the two sides of the boundary, even though the ratio $Fe^{2+}$:$Fe^{3+}$ changes from 2:1 in wüstite to 1:2 in magnetite. The conductivity depends only very slightly on the temperature. We propose that the charge carriers are essentially free and that their concentration is equal to that of $Fe^{3+}$ in wüstite and that of $Fe^{2+}$ in magnetite. The mean free path by the Drude theory is less than 1 A; therefore a band picture is probably not appropriate.

**TA8. Madelung Constant of Selected Metal Azides.** ROBERT C. MCMILLAN, *Engineer Research and Development Laboratories.*—The Madelung constant of Na, K, Ag, Cu, Rb, Cs, and Tl azides has been calculated by the Ewald method assuming that the charge is centered on the central nitrogen atom of the azide ion. Interpretation of the values of the Madelung constant of the above compounds will be attempted.

**TA9. Elastic Constants of Rutile ($TiO_2$).** J. B. WACHTMAN, JR., W. E. TEFFT, AND D. G. LAM, JR., *National Bureau of Standards.*—The six elastic compliances of rutile have been determined by a resonance technique. The specimens were slender, cylindrical single-crystal rods which were annealed and oxidized. The compliances are: $s_{11}=6.47\pm.08$, $s_{33}=2.585\pm.008$, $s_{44}=8.01\pm.09$, $s_{66}=6.79\pm.54$, $s_{12}=-4.49\pm.34$, $s_{13}=-0.70\pm.06$; all in units of $10^{-13}$ cm²/dyne. The elastic constants, computed from the compliances by matrix inversion, are: $c_{11}=3.58\pm.56$, $c_{33}=4.79\pm.22$, $c_{44}=1.25\pm.01$, $c_{66}=1.47\pm.12$, $c_{12}=2.67\pm.56$, $c_{13}=1.70\pm.38$; all in units of $10^{12}$ dynes/cm². The comparatively large uncertainty in $s_{66}$ results from lack of a specimen of appropriate orientation. The value $c_{33}=4.6\pm.4$ found by Vick, Hollander, and Brown[1] is supported in contrast to the value $c_{33}=1.9$ predicted by Dayal and Appalanarasimham from Raman and infrared spectra and quoted by Vick *et al.*

[1] G. L. Vick, L. E. Hollander, and A. E. Brown, Bull. Am. Phys. Soc. Ser. II, **4**, 463 (1959).

**TA10. Etching Effects on NaCl Bombarded with 40-Mev Alpha Particles,** M. HACSKAYLO, *NASA Lewis Research Center.*—The bombardment of sodium chloride crystals with 40-Mev alpha particles induces a plane of high damage.[1] Dislocation etch pits revealed by the Moran etchant[2,3] shows that the density of pits on the colored surface perpendicular to the alpha-bombarded crystal surface decreases with increasing flux. Above $5\times10^{15}$ alpha particles/cm², the etch-pit density is reduced substantially to zero. The uncolored back portion of the crystal shows no diminution of pits and a pronounced demarcation boundary exists at the colored end-range. The number of etch pits of the colored portion are restored to original density upon bleaching the crystal.

[1] M. Hacskaylo, Bull. Am. Phys. Soc. Ser. II, **5**, 184 (1960).
[2] P. R. Moran, J. Appl. Phys. **29**, 1768 (1958).
[3] Stearns, Pack and Lad, NASA TN D-75 (1959).

**TA11. Photoconductivity of Freshly Prepared and Irradiated $TlN_3$.** F. F. CARLSON, *Engineer Research and Development Laboratories.*—Freshly prepared $TlN_3$ was exposed to monochromatized incandescent light (300-w tungsten lamp) in the range from 6000 A to 3000 A. The resolution of the scanning monochromator and the electrometer was 30 A. At room temperature, photoconductivity peaks were observed at 4280 A and 3300 A. At liquid air temperature the peak at 4280 A shifted to 4000 A. The ultraviolet peak was not detectable. After the crystals were irradiated, the photoconductivity was greatly diminished. The peak at 4280 A still persisted but the response rapidly decreased towards the ultraviolet. The irradiated $TlN_3$ was prepared by irradiating the crystal with the full force of a 300-w tungsten projection lamp for 30 min and then with a 100-w Hg vapor lamp for 30 min. It will be attempted to interpret the change of photoconductivity of the several samples.

**TA12. Optical Bleaching and Recovery of *F* Centers.*** L. I. GROSSWEINER AND LORETTA E. SILVERMAN,† *Illinois Institute of Technology.*—*F* centers in KCl are optically bleached at 25°C with an initial rate of 13.9±0.07 ev per *F* center. The coloration is recovered on further x-raying at 25°C according to $(1/n)=(1/n_0)+(E_0/E)$, where $E$ is the absorbed x-ray energy (ev), $n$ is the number of recovered *F* centers, $n_0$ is the number of *F* centers optically bleached before recovery, and $E_0$ is the initial rate of recovery, 73±5 ev per *F* center for Harshaw KCl. The differential rate law leading to this equation is consistent with a bimolecular recombination of vacancies and free electrons from only the bleached *F* centers. When optically bleached *F* centers are fully recovered by x-raying, the *M* and *R* bands return to the condition before bleaching, indicating that the net effect of x-raying optically bleached *F* centers is to transfer electrons from *M* and *R*

centers to the original vacancies. The darkening of fresh KCl does not follow the above equation, except in the first stages where vacancies are already present; $E_0$ in this case is 81 ev per $F$ center, the same order as for fresh NaCl.[1]

* Supported in part by the U. S. Atomic Energy Commission.
† Ohmite Research Fellow, 1958–1959.
[1] H. W. Etzel and J. G. Allard, Phys. Rev. Letters 2, 452 (1959).

**TA13. Polarized Bleaching of $Z$ Centers in KCl.** H. Breedlove and R. J. Friauf, *University of Kansas.*—$Z_1$ and $Z_2$ bands have been produced in additively colored crystals of KCl:Sr, and the $Z_1$ band has also been produced in gamma-ray colored crystals. After one of the $Z$ bands is formed, it is illuminated with polarized bleaching light at the peak of the band. Despite the fact that bleaching has been extended to times considerably in excess of the illumination time required to form the band, no large change in the over-all height of the band occurs in either case, and *no dichroism results for either the $Z_1$ or $Z_2$ band.* In similar experiments on the $F$ and $M$ bands, no dichroism is observed for the $F$ band even after the band height is reduced by 30%, but an appreciable dichroism is observed for the $M$ band in accordance with the results of Ueta. The present results for the $Z$ bands will be compared to earlier results on the $Z_2$ band of Dekeyser and Remaut and of Chiarotti, Fumi, and Giulotto, and the implication of these results for the $Z$ center models proposed by Pick and by Seitz will be discussed.

**TA14. Paramagnetic Resonance of $Z$ Centers in KCl** G. E. Conklin and R. J. Friauf, *University of Kansas.*—Room temperature paramagnetic resonance measurements have been made on crystals of KCl which contain about $10^{-4}$ mole fraction of strontium and which exhibit the $Z_1$ optical absorption band. A definite correlation is observed between the shift in paramagnetic resonance characteristics and the relative magnitude of the $Z_1$ and $F$ center optical absorption bands. No shift in g value from that of the $F$ center is observed, but the width of the absorption curve increases with increasing $Z_1$ to $F$ center ratio. By an extropolation method the peak to peak width of the derivative absorption curve is found to be $62\pm2$ oersted. This width is slightly smaller than that reported by earlier investigators. Preliminary results indicate that the $Z_2$ center paramagnetic resonance absorption is somewhat broader than that of the $Z_1$ center. These results can be understood qualitatively in terms of present models of the $Z$ centers.

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## Wednesday Afternoon at 2:00

National Bureau of Standards, East Building

(H. Suhl presiding)

### *Solid-State Physics, II*

**U1. Orientation Effects in van der Waals Crystals.*** Herbert Jehle, *George Washington University.*—The London-van der Waals interaction between a pair of molecules depends on the distribution of molecular polarizabilities over the frequency spectrum (mainly in the far ultraviolet) and on the mutual orientation of the nearest-neighbor molecules.[1] In situations in which the London-van der Waals force constitutes the principal molecular interaction, this implies (1) that molecules in a liquid medium preferentially associate so that identical molecules become nearest neighbors, and (2) that some orientations of neighboring molecules are preferred before others. The first means that the London-van der Waals force contributes toward the purity of crystal formation, the second means that van der Waals crystals are apt to have neighboring molecules mutually oriented in the way characteristic for dipole-dipole interactions. This orientation effect is, however, usually counteracted by the tendency toward closest packing (also caused by the London-van der Waals force) as the shape of the molecules is not spherical.

* Research supported by the National Cancer Institute.
[1] J. M. Yos, W. L. Bade, and H. Jehle, Phys. Rev. 110, 793, 800 (1958); Proc. Natl. Acad. Sci. 43, 341, 847 (1957); 45, 1360 (1959).

**U2. Hindered-Rotational States in a Crystal.** Harry F. King, *Princeton University* (introduced by D. F. Hornig).—Numerical solutions have been obtained to the Schrödinger equation for a regular tetrahedron rotating in a field of cubic symmetry. The Hamiltonian is a function of the Euler angles and is invariant under the direct product group $\bar{T}_d \times O_h$ or equivalently under $\bar{O} \times O \times i$, where the bar indicates symmetries with respect to a body-fixed reference frame. The interaction potential as well as the wave functions are expanded in a series of angular momentum functions all being reduced to the maximum extent by symmetry considerations. Programs were written for the IBM 650 which compute energy levels and transition probabilities. Dr. Willem Vedder has obtained high-resolution infrared spectra of ammonium-halide-doped alkalie halide crystals at liquid helium temperature. These spectra will be discussed in terms of the computed energy levels.

**U3. "Second" Random Phase Approximation.** H. Suhl, *Bell Telephone Laboratories.*—The random phase approximation (RPA) to the many-electron ground state problem has the advantage that it avoids summation of formally divergent perturbation integrals, But in its usual form it is too crude to demonstrate effects like screening of exchange interactions, damping of plasma oscillations, etc., which have hitherto been treated only by summation methods. An extension of the RPA is presented which remedies these shortcomings in the next order of approximation. For example, in the problem of hole electron pair motion, the ordinary RPA neglects excitation of two-pair states. In the present approximation we retain the two-pair states, and then describe the motion of the double pairs retaining (aside from the "reaction" terms of the medium) the coupling to the single pairs. The nature and extent of the resulting screening of the exchange interaction will be discussed as an example. The method gives a comprehensive view of *all* processes involving one and two pairs in the field. Similarly, one may examine the motion of an added electron, which in the ordinary RPA just gives the single particle Hartree-Fock energy. In the "second" RPA one-electron and (one electron+one pair) motions are coupled together and the Hartree-Fock excitation energy is modified again, in principle, without series summation.

**U4. Faraday Effect Due to Interband and Intraband Transitions in Solids.** Herbert S. Bennett and Edward A.

STERN, *University of Maryland.*—Measurement of Faraday rotation can be used to determine effective masses in solids.[1,2] Previous theoretical calculations of this effect have not included the contribution of interband transitions to the Faraday effect, limiting considerations only to intraband transitions.[1] The Faraday rotation for reflection from and transmission through cubic solids can be expressed in terms of the sum of and the difference between the conductivities for right ($r$) and left ($el$) circularly polarized waves, namely, $\oplus=\sigma_r+\sigma_{el}$ and $\ominus=\sigma_r-\sigma_{el}$. Reality, "strict causality," and finite energy of the incident wave permit us to derive dispersion relations. These are integral equations which relate the real and the imaginary parts of the complex conductivity. The use of the semiclassical theory of radiation with Bloch functions as basis functions yields the $\mathrm{Re}\{\oplus\}$ and the $\mathrm{Re}\{\ominus\}$ due to interband transitions. By combining our results with previous work,[1] the complete expression for the Faraday effect in solids, which now includes both interband and intraband transitions, is obtained.

[1] M. J. Stephen and A. B. Lidiard, J. Phys. Chem. Solids 9, 43 (1958).
[2] E. A. Stern and R. D. Myers, Bull. Amer. Phys. Soc., Series II, 3, 416 (1958).

**U5. Evaluation of Bardeen-Herring Correlation Factors.** A. H. SCHOEN AND R. W. LOWEN, *Convair Scientific Research Laboratory.*—The correlation factor[1] for self-diffusion by the vacancy mechanism, $f$, has been evaluated approximately for all pertinent lattices by Compaan and Haven,[2] whose method involves an analogy to electrical networks. A direct combinatorial treatment yields the following results:

| Lattice | $(1-f)/(1+f)=-\langle\cos\theta\rangle$ |
|---|---|
| Linear chain | $\frac{1}{1}$ |
| Honeycomb layer | $\frac{1}{2}$ |
| Square layer | $1-2/\pi$ |
| Triangle layer | $\frac{1}{2}-\sqrt{3}/\pi$ |
| Diamond | $\frac{1}{2}$ |
| Simple cubic | 0.209841 |
| BCC | $1-\Gamma^4(\frac{1}{4})/8\pi^2-8\pi/\Gamma^4(\frac{1}{4})$ |

The result for the simple cubic lattice is not exact, the last figure being doubtful; work on this case and on the fcc lattice is continuing. The results of Compaan and Haven are generally confirmed.

[1] J. Bardeen and C. Herring, Am. Soc. Metals (Cleveland, 1951).
[2] K. Compaan and Y. Haven, Trans. Faraday Soc. 52, 786 (1956); 54, 1498 (1958).

**U6. Method for the Calculation of Transport Coefficients.*** S. FUJITA, *Northwestern University.*—A general method for the calculation of transport coefficients is proposed. By starting from the exact formulas due to Kubo for coefficients and using the perturbation expansion, static transport coefficients are shown to be given by a time-integral of a sum of Feynman-type diagrams. The following two cases are examined explicitly: electrical conductivity and viscosity coefficient. It is shown that the conductivity usually calculated from Boltzmann's equation is realized in the limits

$$N\to\infty,\quad V\to\infty,\quad \lambda\to 0,\quad \text{and}\quad t\to\infty$$

such that

$$N/V=c=0(1),\quad \lambda^2 t=0(1).$$

Here $N$, $V$, and $\lambda$ are number of electrons, volume of extension, and coupling constant between electron and phonon, respectively; and $t$ is a time of the order of the relaxation time. The viscosity coefficient for an imperfect gas is examined as a first approximation in the different limits $N\to\infty$, $V\to\infty$, $c\to 0$, and $t\to\infty$ such that $\lambda=0(1)$, $ct=0(1)$. Underlying physical situations are discussed with the validity of the resulting expressions.

* Supported by the Office of Naval Research.

**U7. Multi-Phonon Processes Occurring in First-Order Perturbation Theory.** E. FRANZAK* AND M. BAILYN, *Northwestern University.*—In the approximation of plane waves for the electrons in a metal, the electron-lattice perturbation matrix element may be separated into two factors—the first, a matrix element of a single ionic potential screened in some fashion by the conduction electrons, and the second, a matrix element which involves the phonon creation and annihilation operators as a sum of terms representing single phonon processes, double phonon processes, and so on. The shielding effect of the conduction electrons on the ionic potential is most easily estimated by means of a Fermi-Thomas statistical model. In this manner, expressions for the multi-phonon transition probabilities are obtained for all temperatures. Restricting our considerations to temperatures above the Debye temperature, a detailed calculation is made of the effect of double phonon processes (umklapp as well as non-umklapp transitions being included) on electrical conductivity in monovalent metals. The effect of this additional scattering mechanism on electrical conductivity is to produce a reduction of approximately 4% from the single phonon value at 0°C.

* Now at University of Missouri.

**U8. Variational Approach to Diffusion in Inhomogeneous Media.** STEPHEN PRAGER, *University of Minnesota.*—The calculation of the mean flux $P$ of diffusing material through a porous solid is approached through the requirement that in the steady state the rate of entropy production $\sigma$ must be minimized. By regarding the local concentration fluctuation at a point within the solid as a weighted average of the values taken on by the diffusion coefficient in the immediate vicinity, estimates from above can be obtained for both $\sigma$ and $P$. The optimum weighting function is a solution of an integral equation involving two- and three-point averages of the diffusion coefficient.

**U9. Jump Frequencies for Diffusion of Impurities in Ionic Crystals.** JOHN R. MANNING, *National Bureau of Standards.*—When two isotopes of a given impurity are diffused simultaneously in an ionic crystal in the presence of an electric field, values of both $\Delta D/D$ and $\Delta\mu/D$ can be obtained. Here, $\Delta D$ is the difference in diffusion coefficient, $D$, of the two isotopes, and $\Delta\mu$ is the difference in their drift mobilities in the electric field. If the impurity atoms lie on the plane $x=0$ before diffusion and $c_1(x)$ and $c_2(x)$ are the measured concentrations of the two isotopes after diffusion, a plot of $\ln(c_1/c_2)$ vs $x^2$ will give a straight line with a slope proportional to $\Delta D/D$. In addition, $d\ln(c_1/c_2)/dx$, when evaluated at the maximum in either $c(x)$ curve, will give $\Delta\mu/D$. From these ratios, the relative values of the vacancy jump frequencies in the vicinity of the impurity quite often can be calculated. From Chemla's data[1] on the diffusion of $Na^{22}$ and $Na^{24}$ in KCl, relative jump frequencies ($w_{Na}/w_K\sim 4$) and the vacancy-impurity binding energy ($\sim$0.02 ev) can be estimated. These values are consistent with the published values of the diffusion coefficients of Na and K in KCl.

[1] M. Chemla, Ann. Phys. 12, 961 (1956).

**U10. Exact Solution to the Heat Equation in the Case of Peltier Cooling.** ALLEN D. REICH AND JOHN R. MADIGAN, *Roy C. Ingersoll Research Center.*—Heat transfer calculations for a thermocouple circuit functioning as a Peltier cooler have been carried out. The calculations depend upon the exact solution of a one dimensional time dependent heat equation. It is shown that for an unloaded couple the temperature at the cold junction will be less than or equal to the reference junction temperature only for currents in the range from zero to twice the optimum current (i.e., the current that

produces the minimum cold junction temperature). For currents in this range normalized plots of the temperature distribution and of the temperature gradient at any point within couple have been made as a function of distance along the couple. In addition, the temperature at the cold junction has been investigated as a function of time and shown to approach the steady-state values appropriate to any particular multiple of the optimum current at that point with increasing time. It has been shown that one cannot produce a transient thermal spike at the cold junction which is greater in magnitude than the steady-state temperature for the optimum current by initially applying currents greater than the optimum. The possibility of achieving such thermal spikes by superposing a current pulse upon the steady-state current is discussed.

**U11. Exo-Electron Emission of Metal Azides.** H. J. MUELLER, *Engineer Research and Development Laboratories* (introduced by Z. V. Harvalik).—Exo-electron emission from untreated and treated solid sodium and potassium azides, excited by x ray and ultraviolet light, has been studied. The treatment of the specimen consisted of mechanical deformation, heating, and exposure to ultraviolet light and x rays. The exo-electron data are correlated to photoconductivity and absorption spectroscopical data reported in the literature. The influence of the surface structure of the specimen on exo-electron emission is also discussed. Measuring techniques are described.

**U12. Thermoelectric Measurements at Small Area Contacts.** MELVIN CUTLER, *General Atomic.**—If the thermal conductivity $\kappa$ is measured in a region small compared to a characteristic distance for radiation effects $\lambda$, which varies approximately as the cube of the absolute temperature $T_a$, the effect of radiation will be correspondingly small. For most substances, $\lambda \sim 1$ cm at temperatures between 1000 and 2000°C. This suggests that the study of heating at a small size contact ($\sim 10^{-2}$ cm) by means of an electric current will allow measurement of $\kappa$ with little error due to radiation at temperatures as high as 3000°C. One can observe directly a Seebeck voltage $\delta V$ or a change in resistance $\delta R$, which depend linearly on the applied voltage $V$ (Peltier heating) and $V^2$ (Joule heating). The Peltier and Joule coefficients for $\delta V$ are found to be $\alpha^2\sigma T_a/\kappa$ and $(\frac{1}{2})\alpha\sigma/\kappa$, respectively, and for $\delta R(dR/dT)$ they are $(\frac{1}{2})\alpha\sigma T_a/\kappa$ and $(\frac{1}{4})\sigma/\kappa$, where $\alpha$ is the Seebeck coefficient and $\sigma$ is the electrical conductivity. Measurement of $R$, and the two coefficients of $\delta R$ or $\delta V$ leads to values for all of the thermoelectric parameters. The fact that the size and shape of the contact do not enter into the relations makes this approach simple. Perhaps more significant is the fact that measurement at small contacts makes it possible to study very small samples or small regions of inhomogeneous samples.

* John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

**U13. High Current Density Metallic Thermionic Emittors.** H. F. KAISER, *U. S. Naval Research Laboratory.*—Electron sources with high current density emission and physical compactness are much desired for accelerator and plasma research. Possibilities of obtaining large current density thermionic emission from refractory metals and materials by operation closer to their melting points than practiced heretofore is examined. Tungsten has an extrapolated possible emission of 479 amp/cm² at its melting point; moreover, the pulsed electron spectrum of metallic emittors is more monochromatic than for oxides and borides (maximum current densities, 40–100 amp/cm²). Special apparatus for studying this possibility for tungsten will be described together with designs of cathodes in which the effects of electrodynamic and gravity forces on their structural stability are considered. This should also give further insight into anomalous current densities (many times the current density for tungsten at its melting point) observed by Lebedev *et al.*[1] In their work, no facilities for observing thermionic emission existed.

[1] S. V. Lebedev *et al.*, J. Exptl. Theoret. Phys. U.S.S.R. **27**, 5–11, 605–614 (1959).

**U14. Equivalent Proton Complexes in the Composition of Silicates and Their Classification Role.** N. EFREMOV, *600 West 142 Street, New York.*—In the composition of the rock-forming minerals there are some proton complexes of ions characterized by valence 2 and valence 4:

| Valences | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 |
|---|---|---|---|---|---|---|---|---|
| Proton complexes | 4 | | 12 | | 20 | | 28 | |
| Proton complexes | | 8 | | 16 | | 24 | | 32 |

These proton complexes are found as proton domplexes of metal ions in the chemical composition of silicates and may be calculated on the basis of the Rule of Four. The molecules containing these equivalent proton complexes may be divided into "pure line," divergent, and convergent groups:

| Groups | Convergent | "Pure line" | Divergent |
|---|---|---|---|
| Exchangable ions: | AlAl ← MgSi | MgSi or MgMg | MgMg → NaAl |
| Silicate molecules: | $MgAl_2O_4$ | $Mg_2SiO_4$ | $NaAlSiO_4$ |

This concept is useful for explanation of complex chemical composition of minerals and their classification, as some minerals are represented by "pure line" ($Mg_2SiO_4$-olivine), some by divergent ($NaAlSiO_4$-nepheline), others by convergent ($MgAl_2O_4$-spinel), and still others by mixed, convergent-divergent ($H_4K_2Al_3Al_4Si_6O_{24}$-muscovite) groups of molecules.

**U15. APW Method and Its Generalization.*** M. M. SAFFREN, *General Electric Research Laboratory.*—A generalization of the APW method applicable to nonidealized crystal potentials will be given. Moreover, this generalization shows the relation between the APW and OPW methods. The generalization results from a study of the properties of the APW secular matrix. That an $n \times n$ APW matrix have a vanishing determinant is an expression of the requirement that the energy be stationary in the space of *continuous* functions that are describable as a sum of $n$ plane waves in the region of the cell exterior to its inscribed sphere. Though the matrix is finite, it is a transcendental rather than a linear function of the energy and so has an infinite rather than a finite number of roots. Despite this, the following theorems can be shown to apply: the roots of an $n \times n$ APW matrix divide the roots of any $(n+1) \times (n+1)$ APW matrix in which it appears; the set of eigenfunctions of any $n \times n$ APW matrix, though infinite, are orthonormal and diagonalize the energy. Because the APW eigenfunctions have discontinuous derivatives, it is not clear that the eigenfunctions of the $\infty \times \infty$ APW matrix are the true crystal eigenfunctions. Nevertheless, it will be shown that they are, at least in the mean square sense, and that their energies are the true eigenvalues.

* This work forms a portion of the author's doctoral dissertation (May, 1959), MIT.

WEDNESDAY AFTERNOON AT 2:00

Burgundy Room

(L. I. SCHIFF presiding)

## *High-Energy Scattering*

**UA1. Proton-Proton Elastic Scattering at 2.85 Bev.** G. A. SMITH, H. W. J. COURANT, E. C. FOWLER, H. L. KRAYBILL, J. SANDWEISS, AND H. TAFT, *Yale University.*—As a part of the 2.85-Bev proton-proton interaction experiment with the Brookhaven National Laboratory 20-in. liquid hydrogen bubble chamber,[1] we are studying *p-p* elastic scattering. The 2.85-Bev proton beam was formed by elastic (within 1%) scattering from a carbon target within the cosmotron at an angle of $4.2°\pm0.3°$. Out of 460 events which satisfied broad scanning criteria for elastic scattering 251 had primaries satisfying our beam-track criteria and 113 of these were identified as elastic. More stringent premeasurement selection should improve the efficiency of the procedure. The center of mass angular distribution (corrected for scanning efficiency in the interval $\cos\theta$ 0.98 to 0.97) is for $\cos\theta$ from 0.98 to 0.97, 26.8 events; 0.97 to 0.96, 20; 0.96 to 0.95, 14; 0.95 to 0.93, 16; 0.93 to 0.83, 28; 0.83 to 0.53, 3; 0.53 to 0, 0. Data will be presented on the absolute differential cross section and on possible polarization effects.

[1] D. C. Rahm, *Proceedings of the International Conference on High-Energy Accelerators and Instrumentation* (CERN, 1959).

**UA2. Proton-Proton Elastic Scattering at Small Angles.** B. A. MUNIR, *Florida State University,* AND S. J. GOLDSACK, *University of Birmingham, England* (introduced by Dr. Y. C. Tang).—An attempt was made to study small-angle elastic *p-p* scattering at 950 Mev. The experiment was performed inside the vacuum chamber of the Birmingham synchrotron and recoil protons from carbon and polythene targets were detected. *p-p* results were obtained by subtracting the carbon from polythene data. The targets were in the form of very thin foils so that only a small fraction of the recoil energy was lost in the target. The recoil protons were deflected by the magnetic field of the synchrotron through 180° and detected in C2 plates placed inside the vacuum chamber. It was possible to make the beam traverse the target more than once and increase the effective beam intensity by a factor of 10. The relationship between the energy of the recoil proton and its angle of entry into the detector is unique for *p-p* elastic recoils. Recoils corresponding to different scattering angles are displayed at equal intervals along the detector. Also equal areas on the detector correspond to equal solid angles of the scattered protons. Preliminary results on three scattering angles (1.8°, 2.4°, and 2.7°) are available.

**UA3. Proton-Proton Triple Scattering: R at 140 Mev.*** E. H. THORNDIKE, J. LEFRANÇOIS, AND RICHARD WILSON, *Harvard University.*—The proton-proton triple scattering parameter $R$ has been measured at a laboratory energy of 140.5 Mev. The incident beam striking the hydrogen target had its polarization in a horizontal plane. This was accomplished by passing the polarized beam through a solenoid magnet, which caused the spins of the protons to precess 90° about the direction of motion. The sign of the incident polarization could be changed by reversing the direction of current through the solenoid. Protons scattered by the hydrogen target at an angle $\theta_2$ in the horizontal plane were analyzed by a subsequent scattering in a vertical plane. Carbon was used as the analyzing scatterer. Asymmetries from reversing the sign of the incident polarization and from reversing the sense of the analyzing scattering were measured. The zero position of the analyzing scattering angle shifted when the solenoid current was reversed; this shift was measured and the data corrected. The following values of $R$ vs $\theta_2$ (lab) were obtained: 15° $-0.252\pm0.030$; 20° $-0.227\pm0.028$; 25° $-0.271\pm0.035$; 30° $-0.146\pm0.037$; 35° $-0.151\pm0.055$; 40° $-0.047\pm0.080$.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**UA4. Polarization and Differential Cross Section in *n-p* Scattering at 127 Mev.*** RUSSELL K. HOBBIE AND DOUGLAS MILLER, *Harvard University.*—A 2-in. diam liquid hydrogen target was placed in the polarized neutron beam[1] at the Harvard synchrocyclotron. Recoil protons were detected in order to study scattering between 80° and 170° in the center of mass system. The neutron beam is characterized by a 27% energy resolution (full width at half-maximum), and a polarization of $0.42\pm0.03$. The *n-p* polarization was found to vary from $0.375\pm0.039$ at 80° to a minimum of $-0.061\pm0.022$ at 150°, passing through zero at about 125°. The uncertainties assigned to each point include uncertainty in measurement of beam characteristics, as well as counting statistics and all systematic errors. The relative differential cross section has also been measured to an accuracy of $\pm0.04$,

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] D. Miller and R. K. Hobbie, Bull. Am. Phys. Soc. Ser. II, 5, 17 (1959).

**UA5. Polarization in Neutron-Proton Scattering at 210 Mev.*** ROBERT E. WARNER AND JOHN H. TINLOT, *University of Rochester.*—The 210-Mev, 90% polarized proton beam of the Rochester synchrocyclotron has been used to measure the polarization in *n-p* scattering by a $D_2O$-$H_2O$ difference method. Protons and neutrons with the correct angular separation for quasi-elastic *n-p* scattering were counted in fast coincidence. Plastic scintillation counters were used to detect both particles, and the neutron counter was preceded by an anticoincidence counter and absorber to prevent it from counting charged particles. Absorbers in the proton telescope allowed us to reject events in which the second proton recoiled with an energy greater than 10 Mev. The flight times and angular correlations observed were also consistent with quasi-elastic scattering. The polarization reaches a maximum of $+0.364\pm0.043$ for $\theta_{c.m.}=30°$, and changes sign near $\theta_{c.m.}=90°$. The data will be compared with those at other energies and with the predictions of the Signell-Marshak potential.

* Supported in part by the U. S. Atomic Energy Commission.

**UA6. Electron-Proton Scattering at 1.2 Bev.*** K. BERKELMAN, J. CASSELS, AND R. R. WILSON, *Cornell University.*—Further measurements are being made of the scattering of electrons by protons using the Cornell strong focusing synchrotron. Measurements previously reported[1] have been extended to a momentum transfer squared of 26 $f^{-2}$ where the form factor appears to be flattening out. The implications of this result will be discussed. We are also measuring the scattering from deuterium (an internal $CD_2$ target is used). A report of our progress will be given.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] R. R. Wilson, Bull. Am. Phys. Soc. Ser. II, 5, 76 (1960).

**UA7. Nucleon Momentum Distribution in Helium.*** WARREN FENTON STUBBINS, *University of Cincinnati.*—An analysis of the neutron spectrum produced by 910-Mev alphas on beryllium[1] revealed the momentum distribution to be considerably narrower than expected.[2] An independent measurement using 730-Mev protons on a liquid helium target in which the quasi-elastically scattered protons and the recoiling nucleons were required to produce coincidences between two counter telescopes likewise gave a narrow distribution while the carbon nucleon momentum distribution measured at the same time corresponds to previous results.[3] The experimental resolution was obtained by using a hydrocarbon target. The helium nucleon momentum data are fitted with a Gaussian momentum distribution containing a $1/e$ value at a momentum corresponding to a nucleon energy of 5 to 8 Mev. The carbon data are fitted with 16 to 20 Mev as reported. The maximum of the helium distribution is shifted toward smaller angles between telescopes slightly more than the maximum of the carbon distribution is shifted from the maximum of the distribution for the unbound hydrogen in the hydrocarbon target.

* The experimental data were obtained at the Lawrence Radiation Laboratory, Berkeley, under the auspices of the U. S. Atomic Energy Commission.
[1] W. F. Stubbins, Bull. Am. Phys. Soc. Ser. II, 3, 335 (1958).
[2] J. M. Wilcox and B. J. Moyer, Phys. Rev. 99, 875 (1955).
[3] J. B. Cladis, W. N. Hess, and B. J. Moyer, Phys. Rev. 87, 425 (1952).

### *Invited Paper*

**UA8. Cross-Section and Polarization Experiments in Pion-Proton Scattering at 310 Mev; Phase-Shift Analysis.** E. H. ROGERS, *University of California, Berkeley.*

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## WEDNESDAY AFTERNOON AT 2:00

## Caribar-Mural Room

## (A. PAIS presiding)

### *Theoretical Physics VI: Field Theory*

**V1. Quantization of the Yang-Mills Field.*** STUART I. FICKLER† AND RICHARD ARNOWITT, *Syracuse University.*—The quantization of nonlinear theories, such as the Yang-Mills[1] field and general relativity introduces problems that do not appear in a usual linear or quasi-linear field theory like electrodynamics. For example, it will be shown that quantum "Bianchi identities" (those equations which guarantee the consistency of the constraints) depend explicitly on the canonical commutation relations. Further, the variation of the field variables that appear in the generating functions are no longer $C$ numbers in all gauge frames .Thus an examination of the consistency of the quantization of such theories introduces questions that do not appear in other theories. In order to look into these problems, the Yang-Mills field is investigated in a gauge analogous to the radiation gauge of electrodynamics, where the theory has been put into canonical form. By perturbation methods, the theory has been examined to second order in the "isotopic charge" and found consistent.

* Work supported by U. S. Air Force, Aeronautical Research Laboratory, Wright Air Development Center.
† Supported during the Summer of 1959 by the National Science Foundation.
[1] C. N. Yang and R. L. Mills, Phys. Rev. 96, 191 (1954).

**V2. Finite Mass Thirring Model.** P. KAHN, W. D. McGLINN, AND M. DRESDEN, *Northwestern University.*—It does not appear possible to use the exactly two-dimensional soluble model of Thirring, in the explicit form given by Glaser,[1] to test the general requirements imposed on a field theory by Lehmann.[2] Part of the difficulty stems from the fact that the quanta of the field have zero mass causing typical infrared divergencies. As a consequence the renormalized field operators still contain divergent terms. This circumstance makes it impossible to check whether these field operators go over in the weak limit to the free field operators. It is possible, however, to construct an $S$ matrix for a four-dimensional problem involving particles of finite mass. This $S$ matrix goes over to Glaser's expression for the case of two dimensions and zero mass particles. It is now possible to investigate the validity of the Lehmann requirements without being hampered by infrared divergencies. The special feature of the $S$ matrix actually make this check not very straightforward. In particular, there does not appear to be a simple, causal, covariant field, which for finite time interpolates between the in- and out-fields.

[1] V. Glaser, Nuovo cimento 9, 990 (1958).
[2] Lehmann, Symanzik, Zimmerman, Nuovo cimento 6, 319 (1957).

**V3. Nonrelativistic Asymptotic Field Theory.** M. DRESDEN, P. KAHN, AND W. D. MCGLINN, *Northwestern University.*—One of the striking features of the asymptotic form of field theory[1] is the fact that the unitarity condition, which is an exact consequence of the basic postulates, is used so infrequently. This, of course, has its origin in the circumstance that the unitarity condition relates different $\tau$ functions in a nonlinear manner, making its extensive use difficult. One might obtain some insight into the mathematical structure of the unitarity condition by investigating nonrelativistic cases. The nonrelativistic theories considered possess Galilean invariance. It is straightforward to obtain the nonrelativistic version of the Lehman formalism. One uses a complex field and invariance under the Galilean group. The structure of the unitarity condition is the same in the two cases. The fundamental solution of the diffusion equation replaces the $\Delta^+$ function. The recurrence relations for the $\varphi$ functions (which characterize the interaction) are similar to those of the relativistic case. One can investigate just how the special properties of nonrelativistic potentials are reflected in these $\varphi$ functions.

[1] Lehman, Symanzik, Zimmerman, Nuovo cimento 1, 425 (1955).

**V4. Quantum Theory of Isotopic Spin,** D. FINKELSTEIN, *Stevens Institute of Technology,* J. M. JAUCH, *Office of Naval Research, London,* AND D. SPEISER, *Institute for Advanced Study.*—An attempt is described to account for isotopic spin and strangeness in a fundamental way. The idea is that isospin is related to algebraic properties of the $C$ numbers of a new quantum mechanics in much the way that charge is related to the algebraic properties of the complex numbers of

ordinary quantum mechanics. While there are still fundamental obstacles, there are several encouraging circumstances. It is known from correspondence-type arguments that there is only one enlargement of the complex numbers $C$ that leads to an interpretable quantum mechanics, the quaternions $Q$. Quantum mechanics over $Q$ and over $C(Q_{qm}$ and $C_{qm})$ differ in that exact gauge invariance seems impossible in $Q_{qm}$ but not in $C_{qm}$. In particular, there is no strictly gauge invariant quantun field theory of the Dirac-Maxwell type in $Q_{qm}$. The only strictly gauge invariant classical field theory of the Dirace-Maxwell type is $\bar{\psi}\gamma^k\gamma^\mu\partial_\mu\psi$ +interaction+boson, a necessarily massless and parity-flipping (chirality-preserving) fermion interacting with a field like the Yang-Mills **b** field. The irreducible representations of the rotation group are also unusual in $Q_{qm}$. Instead of multiplicity $d=2T+1$, the spin $T$ is associated with $d=2T+1$($T$ integer), $d=T+\frac{1}{2}$ ($T$ half-integer). Thus a doublet is uniquely $T=\frac{1}{2}$ instead of $T=\frac{1}{2}$, while a singlet can be $T=0$ or $\frac{1}{2}$.

**V5. High-Energy Limit of Form Factors.*** S. D. DRELL AND F. ZACHARIASEN, *Stanford University.*—This theorem is proved that, for finite charge renormalization constant $Z_3^{-1}$, the form factors describing any vertex with two particles on the mass shell must vanish at infinite momentum transfer. The relation of this result to the work of Lehmann, Symanzik, and Zimmerman is discussed.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research.

**V6. Analytic Properties of Scattering Amplitudes in Perturbation Theory.** R. EDEN,* C. ENZ, AND J. LASCOUX, *Institute for Advanced Study.*—As a preliminary orientation in the study of the analytical properties of scattering amplitudes above production threshold, the singularity curves to lowest order in perturbation theory (6th order), and for equal mass particles are given. The general approach of Landau[1] is followed and extended to complex values. No complex singularities are found in the "physical sheet." They appear to satisfy Mandelstam's requirement.

* Now at Lawrence Radiation Laboratory, University of California.
[1] Landau, Nuclear Phys. 12 (1959).

**V7. Representation for the Double Commutator.** WALTER GILBERT, *Harvard University.*—A representation for the vacuum expectation value of the double commutator of three field operators will be presented. The representation satisfies the requirement of causality, permits the incorporation of specific information about the limits of the spectra of intermediate states, but fails to embody the Jacobi identity. The representation is derived from the Jost-Lehmann or Dyson representations for the matrix element of a single commutator using the time reversal and TCP invariance of the theory. The derivation is based upon the assumption that two of the fields involved commute for spacelike separations. The assertion that the mass spectra are timelike then enables one to show that the third field has certain causal properties.

**V8. Subsidiary Conditions and Observables.** J. N. GOLDBERG, *Wright-Patterson Air Force Base.*—Bergmann and Janis[1] have found that the use of subsidiary conditions to remove the ambiguity in the Hamiltonian does not simplify the search for observables. None the less, the use of subsidiary conditions and modified field equations may simplify the determination of Poisson bracket relations. Therefore, it is of some interest to see that a modified theory, with a well defined Hamiltonian, can be reduced to the original pathological theory by the imposition of constraints. Recently, Dirac[2] has shown how to remove redundant variables in a theory with constraints involving canonical variables. A similar procedure may be followed in this case. Thus the bracket relations for the observables may be found in terms of the modified field variables. In this form the formalism is similar to a well defined mechanical system to which one adjoins holonomic constraints.

[1] P. G. Bergmann and A. Janis, Phys. Rev. 111, 1191 (1958).
[2] P. A. M. Dirac, Phys. Rev. 114, 924 (1959).

**V9. Classification of Einstein Spaces.** J. F. SCHELL, *Wright-Patterson Air Force Base* (introduced by J. N. Goldberg).—The holonomy group[1] of a $V_4$ has been employed to obtain a classification of four-dimensional Riemannian manifolds. The bivector generators ${}_aL^{\alpha\beta}(\alpha,\beta=1,\cdots,4;\ a=1,\cdots r;\ r=1,\cdots,6)$ of the $r$ parameter group are related to the curvature tensor by means of the relation $R_{\alpha\beta\gamma\delta}=ha_ca_eL_{\alpha\beta}{}^aL_{\gamma\delta}{}^e$, where $ha_ca_e$ is symmetric but not necessarily nonsingular. Each class is characterized by canonical forms for the generators ${}_aL^{\alpha\beta}$ and the metric $g_{\alpha\beta}$. Specialization to Einstein spaces, i.e., spaces for which $R_{\alpha\beta}=\kappa g_{\alpha\beta}$ ($\kappa$=scalar), yields a classification of spaces determining a gravitational field. However, this classification is different from that of Petrov.[2] The tools of our classification, namely, the generators of the holonomy group, are defined by global properties of the space, while the classification of Petrov depends on purely local properties of the space. The relation between the two classifications will be discussed.

[1] J. A. Schouten, *Ricci Calculus* (1954), p. 361.
[2] A. Z. Petrov, Sci Notes Kazan State Univ. 114, 55 (1954).

**V10. On a Relationship between Gravitational and Coulomb Forces.** ANATOL J. SHNEIDEROV, *Institute of Philosophical Inquiry.*—The theory of corpuscular field, published in a preliminary form in 1943,[1] is developed further. A unified two-terms formula is derived for the electrostatic and gravitational forces. The first term contains a reflection coefficient $a$ which becomes unity for totally reflecting bodies, like protons, electrons, mesons, etc., and becomes negligible for ordinary bodies. The second term contains a factor $(1-a)$, and a coefficient of effectiveness $b$, which tends to unity when $a$ tends to unity, and to $1/2.36\times10^{15}$ when $a$ tends to zero. The first term describes interactions between microcosmic bodies placed in the radional field, and the second term is for gravitation force. The absorption coefficient $\beta$ of the radional flux passing through a macrocosmic body was found to be $5.31\times10^{-13}$ cm$^2$/g, and the flux total pressure $J_t$ found to be $5.57\times10^{30}$ dynes/cm$^2$. Gravitational constant $G=J_tb\beta^2=6.67\times10^{-8}$ cm$^3$/g sec$^2$ is constant under usual conditions. Mass of a body and the quantity of matter it contains are never identical, the difference is the "gravitational mass defect." The formula gives correct values for gravitation and Coulomb forces, and the theory finds some evidence in astrophysics, and can be tested experimentally.

[1] A. J. Shneiderov, Trans. Am. Geophys. Union 24, 61 (1943).

**V11. Domain of Validity of the Classical Theory of Radiation Reaction.** T. ERBER, *Illinois Institute of Technology.*—The classical theory of radiation reaction based on the equation (1) $(2e^2/3c^3)(\partial^3x/\partial t^3)+F_{ext}=m(\partial^2x/\partial t^2)$, has been reexamined critically in the light of two general *desiderata*: (I) *The particle trajectories described by* (1) *must exhibit reasonable dynamical behavior.* (II) *The work of radiation reaction forces must really represent* (on the average) *a loss of energy by the particle to the radiation field.* We give a precise analytical formulation of I in terms of the degeneration theory of differential equations. This leads to the conclusion—in agreement with recent work of Plass[1]—that there is in fact a nontrivial class of "external" forces which lead to trajectories satisfying the dynamical condition I. In particular, for a wide variety of cases the exponentially "runaway" solutions of (1) may be eliminated by Dirac's prescription of adjusting the initial acceleration. This adjustment is however so delicate that one can easily prove that *no* solution

of (1) satisfies the classical stability criteria. The radiation condition II leads to a nonautonomous, nonlinear differential equation which severely restricts the class of systems compatible with I. The consistency of the system (1), I, and II seems to have little relevance to the Landau conditions.

[1] G. N. Plass, Bull. Am. Phys. Soc. Ser. II, 4, 294 (1959); and to be published. I am grateful to Dr. Plass for a preprint of his paper.

**V12. Generalization of the Breit Hamiltonian.** EDWARD H. KERNER, *Brookhaven National Laboratory.**—The Wheeler-Feynman scheme of classical electrodynamics, completely eliminating fields in describing interaction charges, can be summarized for any pair by a Lagrangian

$$L_{1\text{at}} = -e_1 e_2 \sum_0^\infty \frac{(-1)^k}{2k!c^{2k}} (D_1 D_2)^k \left(1 - \frac{v_1 \cdot v_2}{c^2}\right) r_{12}^{2k-1},$$

$D_1(D_2)$ signifiying time derivative upon only index 1 (index 2). This expresses—through a reorganization of Taylor expansions of retarded and advanced potentials—the system's infinity of degrees of freedom purely mechanically and contemporaneously. Terminating the series destroys strict covariance; yet, standard conservation laws always are easily formulated, as is (via Ostrogradsky's method) a *single-time* Hamiltonian. Quantization appears straightforward for spinless, but not Dirac particles. However, "private" Hamiltonians $H_1, H_2$ for each particle exist, allowing an interpretation of $D_1 D_2 U$ as $(ik)^{-2}[(U_2, H_2), H_1]$. This gives (to terms in $e^2$) Breit's Hamiltonian with addenda simply related to Moller scattering; further systematic corrections seem possible, giving in all a double expansion in $e^2$ and $c^{-1}$ for which condensation into a series is just $c^{-1}$, rather than the customary $e^2$ ,can be studies.

* On leave from the University of Buffalo. Work assisted by the U. S. Atomic Energy Commission.

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## WEDNESDAY AFTERNOON AT 2:00

## Sheraton Hall

## (L. A. DUBRIDGE presiding)

### *Invited Papers*

**VA1. The Early Anti-Proton Work.** OWEN CHAMBERLAIN, *University of California, Berkeley.* (30 min.)

**VA2. Nuclear Properties of Antiprotons.** EMILIO SEGRÈ, *University of California, Berkeley.* (30 min.)

**VA3. Charge Exchange of Antiprotons and Annihilation of Antineutrons in Hydrogen.** J. A. POIRIER, *University of California, Berkeley.* (30 min.)

**VA4. Development of Bubble-Chamber Techniques.** D. A. GLASER, *University of California, Berkeley.* (30 min.)

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## WEDNESDAY AFTERNOON AT 2:00

## Adams-Hamilton Room

## (L. M. BRANSCOMB presiding)

### *Optical and General Physics*

**W1. Excitation of Triplet Spectra in Helium by 200-kev Proton Impact.*** R. H. HUGHES, *University of Arkansas.*—Several triplet lines of helium have been observed during the passage of 200-kev protons through an atmosphere of helium at pressures of 16 $\mu$ and 32 $\mu$. Direct excitation of the triplet system would be in violation of the Wigner spin conservation rule. Analysis of the pressure dependence shows that two excitation mechanisms are competing at these pressures. Cross-section calculations on excitation into the $4^3D$ level confirm that one mechanism is collisions of the second kind. This presumably represents the first observation of this mechanism in proton impact studies. The mechanism which shows a linear dependency on the pressure is yet undetermined. Preliminary measurements indicate that at 32 $\mu$ these two mechanisms play about equal parts in exciting the $4^3D$ level. Absolute cross-section measurements will be presented.

* Supported by the U. S. Air Force Cambridge Research Center.

**W2. *L* Series $\gamma$-Ray Spectra of Zirconium.*** ROBERT J. LIEFELD† AND E. LEONARD JOSSEM, *The Ohio State University.*—The complete *L* series emission spectrum and the absorption spectra in the neighborhood of the $L_{II}$ and $L_{III}$ edges has been obtained for metallic zirconium. The precision two-crystal spectrometer used to take these data employed quartz analyzing crystals, a proportional counter detector, and well regulated x-ray sources. Principal interest centers in the information which can be deduced about the density of states (times transition probability) in the conduction band of zirconium. Preliminary analysis of the $L\gamma_1$ emission line, including corrections for resolving power and inner state width, indicates that the density of occupied *s*- and *d*-type states has a sharp high-energy edge and tails off smoothly at lower energies. Absorption spectra obtained with chemically etched bulk metal foils also indicate a relatively smooth variation of the density of unoccupied states. Absorption spectra of evaporated films and metal powder samples show strong initial maxima believed to be the result of oxidation of the sample.

* Work supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
† Now at Cornell University.

**W3. Performance of a Be-Cu Photomultiplier in the 100 A to 300 A Region.*** D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University.*—Instrumental details of a photon-counting spectrometer suitable for absorption studies in the soft x-ray

region have been given in a previous report.[1] The present paper will describe a series of performance tests of the photon counter in connection with attenuation measurements in the spectral range mentioned in the title. Data taken under a variety of counting conditions dealing with such parameters as source intensity, interdynode voltage, and amplifier gain will be presented and discussed. A summary of the data on the absorption coefficients of chromium and copper at $\lambda = 180$ A amply confirm the *a priori* expectation that a unique value of the absorption coefficient should result from measurements obtained under a variety of experimental conditions.

* Supported by the Office of Naval Research.
[1] D. E. Bedo and D. H. Tomboulian, Bull. Am. Phys. Soc. Ser. II, 4, 419 (1959).

**W4. Stock Prices as Brownian Motion in a Periodic Lattice.** M. F. M. OSBORNE, *U. S. Naval Research Laboratory.*—Since the normal distribution which characterizes Brownian motion[1] can arise in a great variety of stochastic processes, it is necessary to examine the "microscopic" details of such processes in order to distinguish them. Histograms of closing prices with respect to eights reveal a characteristic clustering at integers, halves, quarters, and odd one-eights in descending preference, like the markings on a ruler. Maxima cluster on the low side of integers and half-integers, minima on the corresponding high side. Thus the diffusion of stock prices is akin to diffusion in a one-dimensional, diatomic crystal lattice. The over-all distribution has a fluted structure, like sand on a tilted washboard. This phenomenon is a microscopic demonstration of "resistance" and "support" and helps to explain the very small values of serial correlations of price differences.[2]

[1] M. F. M. Osborne, Op. Research 7, 807 (1959).
[2] M. G. Kendall, J. Roy. Statist. Soc. A116, 11 (1953).

**W5. Inelastic Energy Loss in High-Energy Atomic Collisions.*** ARNOLD RUSSEK AND CHONG KOOK LEWE, *The University of Connecticut.*—Recently, some experimental data has been obtained on the inelastic energy associated with the scattering of many electron atoms.[1] This was accomplished by an analysis of the recoiling target atoms. In collisions of $Ar^+$ on Ar and $Ne^+$ on Ar at 75 kev, both "hard" and "soft" secondaries were observed at a fixed angle of recoil of the target atom. An interpretation of this data is here considered via the introduction of two "coefficients of restitution" describing the changes (before and after the collision) in the magnitudes of the components of relative velocity parallel and perpendicular to the direction of relative motion at minimum nuclear separation, $e_{\parallel}$ and $e_{\perp}$. It is found that the angular distribution of scattered primaries is somewhat affected by the value of $e_{\perp}$. On the other hand, the angular distribution of scattered secondaries is hardly affected by $e_{\perp}$ at all, but is critically dependent on $e_{\parallel}$. From the relative numbers of soft to hard secondaries at a given recoil angle, information can be obtained about the behavior of $e_{\parallel}$ and, therefore, of the inelastic energy as a function of impact parameter.

* Supported in part by a grant from Ramo-Wooldridge.
[1] V. V. Afrisomov and N. V. Federenko, Zhur. Tekh. Fiz. 27, 2557 and 2573 (1957).

**W6. Thermodynamic Functions of Thermosetting Polymers.** M. C. PETREE, *U. S. Naval Ordnance Laboratory.*—The specific heat of seven amorphous thermosetting polymers has been measured as a function of temperature from 25 to 160°C.[1] The polymers were epoxides, a polyamide-epoxide copolymer, diallyl phthalate, and a polyester. The specific heat curves revealed four glass transitions. The corresponding entropy curves exhibit small changes in slope at the glass transition temperatures. Enthalphy plots were straight or slightly curved. Plotting the slope of the entropy curve ($C_p/T$) offers a sensitive way of locating the glass transition temperature, but is little better than the $C_p$ curve itself. The data may be useful to those engaged in deciding whether the glass transition is kinetic in nature or is a thermodynamic second-order transition.

[1] R. W. Warfield, M. C. Petree, and P. Donovan, Naval Ordnance Lab. Rept. 6255.

**W7. Magnetically Suspended Molecular Pump Rotors.*** J. W. BEAMS AND C. E. WILLIAMS, *University of Virginia.*—Magnetically supported rotors have been used in molecular pumps[1] to produce very high vacua. The rotors are made of alloy steel and the stators of nonmagnetic stainless steel, aluminum alloy, or copper. The vacuum chambers are made of glass or of stainless steel. The supporting electromagnet is situated outside and above the vacuum chamber. The entire pumping system may be baked out. The rotor is driven by a rotating magnetic field produced by field coils outside the vacuum chamber. With pressures below $10^{-8}$ mm Hg in the high-pressure inlet the rotor drive may be removed after reaching operating speed for the rotor will coast during the remainder of the usual pumping period. The use of small magnetically suspended rotors as absolute pressure gauges for very low pressures will be discussed.

* Supported in part by U. S. Navy Bureau of Ordnance.
[1] J. W. Beams, Science 130, 1406 (1959).

**W8. New Method for Measuring Sputtering in the Region Near Threshold.** DANIEL MCKEOWN, *Convair (Astronautics) Division, General Dynamics Corporation.*—In a recently constructed molecular beam apparatus a new low-level sputtering erosion gauge has been tested. The gauge consisted of a 10-Mc, gold-plated, quartz oscillator whose frequency was sensitive to the removal of substantially less than $10^{-8}$ g of gold. The gold plating was sputtered from the crystal by a singly charged argon beam at normal incidence. The beam energy was varied between 0 and 100 ev. Its intensity was $3 \times 10^{-6}$ amp $cm^{-2}$. Since the sensitivity of the gauge is very high, sputtering rates were determined by measuring the increase in crystal frequency after only 30 sec in the beam. Rates for other metals or for nonmetals can be measured by using them to plate or overplate the crystal. The gauge has been used as a detector of neutral particles whose energy was above the threshold of sputtering. The process of deposition of the beam on the crystal can also be detected by a corresponding frequency decrease.

**W9. Construction of Large Metal Ultra-High Vacuum Systems, Using Oil Diffusion Pumps and Neoprene Rubber Gaskets.** I. FARKASS AND J. C. SIMONS, JR., *National Research Corporation.*—Construction of large metal ultra-high vacuum system, with volumes ranging from ten liters to several hundred thousand liters, capable of pressures in the $10^{-10}$ mm Hg range is described. Use of high-speed oil diffusion pumps, only liquid nitrogen cooled cryogenic surfaces, and baking at 200°C to reach these low pressures is discussed. A description is given of an easily demountable, neoprene rubber O-ring seal which has been used successfully in the $10^{-10}$ mm Hg range. Experimental evidence is cited that, contrary to earlier reports, oil diffusion pumps maintain their pumping speeds well below $10^{-8}$ mm Hg.

**W10. Ultra-High Vacuum Systems for Space Simulation and Surface Investigations in the $10^{-10}$ mm Hg Range.** J. C. SIMONS, JR., E. S. CANDIDUS, AND I. FARKASS, *National Research Corporation.*—With the methods described in the previous abstract, large metal ultra-high vacuum systems were built. Electrical feed-throughs, windows, gauges, and rotary seals were connected to a 47-cu ft and to a 3-cu ft volume system. Application of these tools to space simulation

problems and to investigation of surface behavior will be discussed. Data on creep-rupture experiments intended to measure surface influence will be presented.

**W11. Escape Mechanisms for the Lunar Atmosphere.*** S. F. SINGER AND E. J. ÖPIK, *University of Maryland.*—Because of the moon's low gravitational potential it is generally assumed that all light gases escape but that krypton and xenon are retained over times long compared to the age of the moon and accumulate an atmosphere of several mean-free-paths' thickness. We find, however, that Xe and Kr will escape when we consider that photoionization halves the effective molecular weight. This conclusion must be modified if the moon's magnetic field exceeds the interplanetary field. However, a more powerful ejection mechanism exists for an atmosphere which is very thin, essentially an exosphere, as a consequence of the assumption that the moon is positively charged due to solar uv photons. We note that a gas atom in describing a ballistic orbit starting at the moon's surface has a finite probability of being photoionized. If this occurs on the upward portion of the trajectory, the resulting ion is expelled electrostatically. The magnitude of the effect depends in detail on the relation between screening distance of the lunar surface charge to average altitude of the ballistic orbit. However, under most reasonable assumptions and even in the presence of a magnetic field the mechanism is fast enough to get rid of all gas atoms evolving from the moon's interior.[1]

* Supported by the U. S. Air Force Geophysical Research Directorate.
[1] W. F. Edwards and L. B. Borst, Science **127**, 325 (1958).

**W12. Formation of D, Li, Be, and B in an Expanding Universe.*** RALPH A. ALPHER, *General Electric Corporation*, JAMES W. FOLLIN, JR., *Applied Physics Laboratory, The Johns Hopkins University*, AND ROBERT C. HERMAN, *General Motors Research Laboratory.*—We have integrated the differential equations for light element abundances in the expanding cosmology previously described.[1] We included all exothermic reactions and estimated cross sections where no measurements on the direct or inverse reactions exist. At 200 sec ($kT=29$ kev) synthesis is essentially complete. The corresponding nuclear density for best fit is approximately $2.5\times10^{17}$/cc and the abundances are all $1.5\pm20\%$ of present measurements relative to hydrogen. This indicates that $\frac{1}{3}$ of the solar system matter has been formed into stars, modified by proton reactions, and ejected into space.

* This work was partially supported by a Bureau of Naval Weapons, Department of the Navy contract.
[1] R. A. Alpher, J. W. Follin, Jr., and R. C. Herman, Phys. Rev. **92**, 1347 (1953).

**W13. Physical Conditions in an Expanding Universe at Galaxy Formation and at Present.*** JAMES W. FOLLIN, JR., *Applied Physics Laboratory, The Johns Hopkins University.*—As the universe expands adiabatically from the conditions for nuclear synthesis,[1] the matter cools with $\gamma=5/3$ and the radiation with $\gamma=4/3$. Compton scattering maintains equality of matter and radiation temperatures until hydrogen neutralization. At $T=1000°$K ($t=5\times10^4$ yr and $n=30$) recombination starts and proceeds to 99% completion. The neutralization is limited by radiative capture rates and trapping of resonance radiation. The trapped Lyman $\alpha$ radiation is released as a broad line which should be observable between 10 and 100 $\mu$ when looking toward intergallactic space. Experimental detection of this line will lead to significant information about the universe and details of its structure will be presented.

* This work was partially supported by a Bureau of Naval Weapons, Department of the Navy, contract.
[1] R. A. Alpher, J. W. Follin, Jr., and R. C. Herman, Bull. Am. Phys. Soc. Ser. II, **5**, 287 (1960).

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## WEDNESDAY AFTERNOON AT 2:00

## Continental Room

## (M. A. TUVE presiding)

## *Neutron Physics I*

**WA1. Neutron Moderation to Low Temperatures.** LYLE B. BORST, *New York University.*—The moderation of neutrons to low temperatures requires mechanisms only imperfectly understood. Neutrons have been moderated to 4°K in ice immersed in liquid helium. The Maxwell distribution shows an effective cross section for a $1/v$ absorber (indium) 8.5 times that of room temperature, almost precisely the inverse ratio of effective velocities. The moderation mechanism is thought to involve rotational transitions of the water molecule associated with a nuclear spin flip analogous to the ortho-para transition in molecular hydrogen. The estimated transition energy for a free gas molecule is 0.001/ev, 30% higher than on inelastic process observed by Hughes.[1] While rotational transitions are not observed in condensed systems by conventional spectroscopic methods, they have been detected in a dilute solution of water in a nonpolar solvent such as carbon tetrachloride.[2]

[1] D. J. Hughes, H. Palevsky, W. Kley, and E. Tunkelo, Phys. Rev. Letters **3**, 91 (1959).
[2] L. B. Borst, A. M. Buswell, and W. H. Rodebush, J. Chem. Phys. **6**, 61 (1938).

**WA2. High-Resolution Fast Chopper Measurements.*** W. C. OLSEN AND P. P. SINGH, *Atomic Energy of Canada Limited Chalk River Laboratories*, AND R. E. CHRIEN, H. PALEVSKY, AND D. J. HUGHES, *Brookhaven National Laboratory.*—The 90-m flight path for the joint BNL-AECL fast chopper program at Chalk River has been completed recently and put into operation. This installation is intended for use in high-resolution neutron transmission measurements with a BNL-type fast chopper situated at the NRU reactor. Neutrons are detected with a $BF_3$ detector consisting of an array of 384 counters in a common gas atmosphere. Neutrons are timed by a modified version of the Brookhaven 1024-channel time analyser with punched tape output and automatic data plotting accessories. A net counting rate of 1 count per channel per min is obtained with 1-$\mu$sec channels at a chopper speed of 10 000 rps. This rate is comparable to that obtained at Brookhaven with a 20-m flight path. The over-all resolution, approximately 15 m$\mu$sec per m has been checked experimentally by examining resonances in Mn and $U^{238}$. The amount of overlap neutrons has been determined by using resonance and $1/v$ filters. The characteristics of the experimental system will be discussed and typical open beam spectra will be presented. It is expected that this facility will be especially useful for total neutron cross section measurements in the region from 100 ev to 10 kev.

* Work carried out under the auspices of the Atomic Energy of Canada Limited and the U. S. Atomic Energy Commission.

**WA3. Thermal Neutron Densities at an Air-Earth Boundary.** R. L. MATHER AND F. M. TOMNOVEC, *U. S. Naval Radiological Defense Laboratory.*—The thermal neutron distribution near the surface of large samples of soil and water has been investigated as a function of sample composition under conditions which we believe simulate that of large scale neutron fields such as the cosmic-ray neutron field. The thermal neutron density generally reaches a maximum a few inches below the soil surface. The maximum is generally 50–100% greater than that at the surface. The surface thermal neutron density is a function of the hydrogen content of the soil—increasing 135% for each increase of 1% by weight of hydrogen in the sample. Measurements were made by the cadmium difference on gold activation using neutrons from 12-Mev protons on beryllium at the University of California 60-in. cyclotron.

**WA4. Thermal Neutron Absorption Cross Sections by the Pulsed Source Method.** J. W. MEADOWS AND J. F. WHALEN, *Argonne National Laboratory.**—The thermal neutron absorption cross sections of a number of elements have been determined by comparing the time dependence of the neutron flux in distilled water with that in a water solution of the sample with the same geometric buckling. After making some small corrections arising largely from the change in the number of hydrogen atoms per $cm^3$ in the solution the ratio curve gives the absorption cross section of the solute averaged over the neutron flux spectrum. For a $1/v$ cross section the 2200 m/sec cross section can be directly computed. Elements measured are Li, B, Cl, Mn, Co, Se, Br, Ag, In, I, Sm, Eu, Gd, Dy, and Hg.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**WA5. Total Neutron Cross Sections of C, BeO, Fe, and Cd.** R. B. WALTON, N. F. WIKNER, J. L. WOOD, AND J. R. BEYSTER, *General Atomic.**—The total neutron cross sections of C, BeO, Fe, and Cd were measured in the energy range from 0.003 to 10.0 ev using pulsed-beam time-of-flight techniques. Neutrons having energies in this region were obtained by moderating fast neutrons produced by bombarding a thick lead target with 25-Mev electrons from an electron linear accelerator. Transmissions of the samples were measured using a 16-m collimated flight path and a bank of 30 $BF_3$ counters to detect the neutrons. The Cd cross sections are in agreement with those given in BNL 325, but some significant differences were observed for BeO, C, and Fe. In particular, over a broad energy region centered near 0.025 ev, the carbon cross section is about 15% higher than that previously reported.[1] The diffusion coefficient for neutrons in thermal equilibrium in carbon has been calculated using the new carbon total cross section data and is in agreement with a previously measured value.[2] The implication of these results on the thermal absorption cross section of carbon will be discussed.

* A Division of General Dynamics Corporation.
[1] P. A. Egelstaff, J. Nuclear Energy 5, 203 (1957).
[2] A. V. Antonov *et al.*, Geneva Papers, 5, 661 (1955).

**WA6. Absorption Neutron Cross Section of $B^{10}$ and Normal Boron.*** G. J. SAFFORD, T. I. TAYLOR, B. M. RUSTAD, AND W. W. HAVENS, JR., *Columbia University and Brookhaven National Laboratory.*—The total neutron cross section of $B^{10}$ has been measured at neutron energies between 0.00291 ev and 0.1 ev with the Columbia neutron crystal spectrometer. The isotopic enrichment of the $B^{10}$ sample was determined by two independent mass spectrometer measurements to be 92.84±0.06 at. % $B^{10}$ (KAPL) and 92.8±0.1 at. % $B^{10}$ (ORNL). The $B^{10}$ absorption cross section, obtained by subtracting the small known scattering cross section from the measured total cross section, follows the relationship $E6a = 612.3 \pm 2.4$ b-ev$^{\frac{1}{2}}$ in this energy region. The resulting value of $6a(B^{10})$ at 0.0253 ev is 3849±15 b. Similar measurements on a sample of normal boron (Argonne-Brookhaven standard) gave a value of 0.0253 ev of 764±3 b for $6a$. Isotopic analyses for the $B^{10}$ content of this sample are 19.8±0.2 at.% $B^{10}$ (KAPL) and 19.8±0.1 at.% $B^{10}$ (ORNL). The above absorption cross sections for $B^{10}$ and the standard sample yield a value of 19.85±0.11 at.% $B^{10}$ in the normal sample, which is in good agreement with the mass-spectrometer determinations.

* Research supported by U. S. Atomic Energy Commission.

**WA7. Polarization of 3.4-Mev Neutrons Scattered by S, Cu, and Zn.*** G. C. COBB,† H. O. FUNSTEN, T. G. WILLIAMSON, AND F. L. HEREFORD, *University of Virginia.*—Partially polarized 3.4-Mev neutrons were elastically scattered by S, Cu, and Zn and the right-left asymmetry observed at various scattering angles between 30° and 150°. With knowledge of the polarization of the incident neutrons (≈14%), the elastic scattering polarization, $P_{el}(\theta)$, was inferred from the measured asymmetry for each scatterer. In the case of all three scatterers the polarization can be correlated with recently measured differential cross sections,[1] nodes in the polarization and minima in the cross sections occurring at the same scattering angles. The observed values of polarization for Cu and Zn are in close agreement at all scattering angles as are the differential cross sections.[1] Maximum polarization for these elements is about 35% and occurs at a scattering angle of about 120°.

* Supported by the U. S. Atomic Energy Commission and Office of Ordnance.
† U. S. Rubber Company Fellow.
[1] M. K. Machwe, D. W. Kent, Jr., and S. C. Snowden, Phys. Rev. 114, 1563 (1959).

**WA8. Measurement of Internal Magnetic Fields in a Ferromagnet Using 3.4-Mev Polarized Neutrons.*** T. G. WILLIAMSON, G. C. COBB,† H. O. FUNSTEN, AND F. L. HEREFORD, *University of Virginia.*—The internal magnetic field in a ferromagnet was determined by measuring the change in the polarization of a beam of polarized 3.4 Mev neutrons which had passed through magnetized iron. A beam of polarized neutrons was obtained from the $D(d,n)He^3$ reaction using 1.0 Mev deuterons on a heavy ice target in a Van de Graaff accelerator. The polarization was found from the right-left asymmetry produced by scattering of the beam from a carbon analyzer.[1] The ferromagnetic substance through which the beam passed was a 6.7-cm thick piece of vanadium Permendur (49% Fe, 49% Co, 2% Va) which was placed between the poles of an electromagnet. The magnetic induction in the Permendur was determined by standard ballistic galvanometric techniques and within experimental error agreed with that calculated from the depolarization produced. Thus the field effective for precessing the neutron spins is the magnetic induction $B$ within experimental error.[2]

* Supported by the U. S. Atomic Energy Commission and Office of Ordnance Research, U. S. Army.
† U. S. Rubber Company Fellow.
[1] W. P. Bucher, W. B. Beverly, G. C. Cobb, and F. L. Hereford, Phys. Rev. 115, 960 (1959).
[2] This and the preceding paper were placed in a nuclear-physics session by request.

**WA9. Scattering of Polarized Neutrons by Spin Waves in Magnetite.** G. A. FERGUSON, JR., AND A. W. SÁENZ, *U. S. Naval Research Laboratory.*—The present work is designed to check experimentally an approximate theoretical formula for polarized monochromatic slow neutrons scattered predominately by "acoustic" magnons of sufficiently long wavelengths in suitable ferrimagnets.[1] For crystal setting close enough to a Bragg setting with $\tau \neq 0$, this formula states that

the cross section for such scattering into all possible final neutron states is given by $[1+(\mathbf{e}_0\cdot\boldsymbol{\kappa})^2\pm 2f(\mathbf{e}_0\cdot\boldsymbol{\lambda})(\mathbf{e}_0\cdot\boldsymbol{\kappa})]$ times a function independent of $f$, $\boldsymbol{\lambda}$, and $\boldsymbol{\kappa}$, where $\mathbf{e}_0=\boldsymbol{\tau}/|\boldsymbol{\tau}|$, $\boldsymbol{\kappa}$, and $\boldsymbol{\lambda}$ are unit vectors parallel to the respective directions of spin polarization of the scatterer and of the incident neutrons, $f$ is the polarization of the latter, and $+$ and $-$ correspond to magnon emission and magnon absorption, respectively. We have employed neutron diffraction techniques to study the spin-wave scattering of polarized thermal neutrons in the vicinity of the (111) reciprocal lattice point in magnetite. Measurements at 204°C for $\mathbf{e}_0$, $\boldsymbol{\lambda}$, and $\boldsymbol{\kappa}$ approximately colinear confirm the foregoing prediction qualitatively.

[1] A. W. Sáenz, J. Appl. Phys. 31 (April Suppl., 1960) (to be published).

**WA10. Neutron Diffraction in Liquids According to the "Smeared Potential" Model.** ARNULFO MORALES-AMADO AND RICHARD K. OSBORN, *The University of Michigan.*—The differential scattering cross section (in angle and energy) for slow neutrons by monoatomic liquids has been investigated using the Lennard-Jones and Devonshire[1] liquid model potential. It can be shown that this "smeared potential" approximates a parabola for values $(2\nu/\mu)^{\frac{1}{2}}a^{-3}\lesssim 0.6$, where "$a$" is the distance between the centers of the cells and $\mu$ and $\nu$ can be obtained from the Lennard-Jones potential $(-\mu r^{-6}+\nu r^{-12})$ and gas-phase data. The model is characterized by the Hamiltonian $H=p^2/2M+M\omega^2r^2/2$ where $\omega(\mu,\nu)$ is the oscillator frequency and $M$ is the mass of an atom in the liquid. The theory has been applied to, and results have been obtained for, Ne, Ar, Kr, Xe, and Pb. The angular cross sections for Ar and Pb compare well with available experimental results,[2,3] and the broadening of the half-height widths at different temperatures of the final neutron energy spectrum for Pb is in better agreement with experimental data[4] than those predicted by the diffusion model.[4]

[1] J. E. Lennard-Jones and A. F. Devonshire, Proc. Roy. Soc. (London) A163, 53 (1937); A165, 1 (1938).
[2] D. G. Henshaw, Phys. Rev. 105, 976 (1957).
[3] B. N. Brockhouse and N. K. Pope, Phys. Rev. Letters 3, 259 (1959).
[4] I. Pelah, W. L. Whittemore, and A. W. McReynolds, Phys. Rev. 113, 767 (1959).

**WA11. Scattering of Cold Neutrons by Liquid Lead.*** H. PALEVSKY, D. J. HUGHES, H. R. MUETHER, AND R. L. STEARNS, *Brookhaven National Laboratory.*—Beryllium filtered neutrons scattered from thin samples of liquid lead, and the spectrum of neutrons scattered at 90° has been measured using the Brookhaven slow chopper apparatus. The spectrum shape has been studied as a function of sample temperatures from the melting point, 600°K, to 735°K. At all temperatures the scattered spectrum exhibits a diffusive type broadening of the sharp beryllium cutoff incident spectrum, and the broadening increases with sample temperature. This result is in contrast with previous measurements on liquid $H_2O$ where no diffusive broadening could be observed.[1] An exact comparison of the neutron data to the measured diffusion constants of Pb is difficult because of the coherent nature of the scattering of neutrons from Pb. However, the variations of the neutron broadening with temperature can be compared directly to the activation energy as determined by diffusion. The neutron data gives an activation energy of 1600 cal/mole as compared to 4000 cal/mole from diffusion measurements. This result is consistent with the idea that the Pb atom executes a number of oscillations in the field of its nearest neighbors before making a diffusive jump.

* Work carried out at Brookhaven under the auspices of the U. S. Atomic Energy Commission.
[1] D. J. Hughes, H. Palevsky, W. Kley, and E. Tunkelo, Phys. Rev. Letters 3, (1959).

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WEDNESDAY EVENING AT 7:30

(Cocktails from 6:30)

Sheraton Hall

(V. F. WEISSKOPF presiding)

***Banquet of The American Physical Society***

After-dinner speaker: L. A. DUBRIDGE

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THURSDAY MORNING AT 9:30

National Bureau of Standards, East Building

(E. BURSTEIN presiding)

***Invited Papers in Solid-State Physics***

**X1. Field Ion Microscopy of the Atomic Structure of Metal Surfaces.** E. W. MÜLLER, *Pennsylvania State University.* (45 min.)

**X2. High-Pressure Studies of Solidified Gases.** J. W. STEWART, *University of Virginia.* (30 min.)

**X3. Magnetoresistance and the Band Structure of PbS, PbSe, and PbTe.** R. S. ALLGAIER, *Naval Ordnance Laboratory.* (30 min.)

**X4. Internal Excited States and the Zeeman Effect of Impurity Levels in Silicon.** S. ZWERDLING, *Lincoln Laboratory, Massachusetts Institute of Technology.* (30 min.)

THURSDAY MORNING AT 10:00

Caribar-Mural Room

(ERNEST AMBLER presiding)

## *Cryogenics*

**XA1. Field Effect in Superconducting and Normal Metal Films.*** M. D. SHERRILL AND R. E. GLOVER, III, *University of North Carolina.*—A thin metallic film on the order of 40 A thick is made one plate of a parallel plate capacitor. An electric field of $10^8$ v/cm across the condensor results in the addition or subtraction of about one charge carrier for each $10^4$ atoms of the film. Changes in the normal state conductivity with charging have been detected, and preliminary measurements of the temperature dependence of the effect have been made for gold and tin. A shift in the superconducting transition temperature upon charging has been observed in tin.

* Supported in part by the Office of Naval Research, the National Security Agency, and the National Science Foundation.

**XA2. Effect of Hydrogen and Deuterium on the Superconducting Transition of Lanthanum.*** G. D. CODY, J. J. HANAK, AND G. T. MCCONVILLE, *RCA Laboratories.*—The effect of hydrogen and deuterium on the superconducting transition of lanthanum has been examined by a mutual inductance method. Samples were prepared by allowing hydrogen or deuterium to come into equilibrium with lanthanum at a sufficiently high temperature to avoid formation of $LaH_2$ or $LaD_2$. The samples were then quenched to room temperature to prevent precipitation of the "compounds." Both hydrogen and deuterium reduce the transition temperature of lanthanum. This reduction, as well as differences between the effects of hydrogen and deuterium, will be discussed.

* This work was supported by the U. S. Air Force.

**XA3. Far-Infrared Transmission through Superconducting Films.*** D. M. GINSBERG † *University of California, Berkeley.*—The far infrared transmission through films of superconducting and normal lead, tin, indium, and mercury at low temperatures (~1.5°K) has been measured in the wavelength region between 0.1 and 1.1 mm. This type of experiment was first performed by Glover and Tinkham,[1] but the accuracy is now improved by changes in optics and radiation detection. The transmission data have been analyzed to find the ratio of the complex conductivity in the superconducting state to that in the normal state as a function of frequency. The width of the energy gap may be estimated from the frequency of the extrapolated cutoff of the real part, $\sigma_1(\omega)$, of the superconducting conductivity. The values so obtained are $4.0\pm0.5$, $3.3\pm0.2$, and $3.8\pm0.3$ $kT_c$ for lead, tin, and indium, respectively, in good agreement with other experiments on bulk samples. An unexpected hump has been found in $\sigma_1(\omega)$ for lead and (tentatively) mercury at low frequencies. This hump may be due to the production of collective excitations or to an anisotropy of the energy gap width.

* Supported in part by the National Science Foundation, the Office of Naval Research, and the Alfred P. Sloan Foundation.
† National Science Foundation Predoctoral Fellow, now at the University of Illinois.
[1] R. E. Glover, III, and M. Tinkham, Phys. Rev. **108**, 243 (1957).

**XA4. Study of the Intermediate State in Superconductors Using Cerium Phosphate Glass.** WARREN DESORBO, *General Electric Research Laboratory.*—The Faraday effect in a cerous nitrate-glycerol solution has been utilized by Alers[1] to observe the intermediate state domains in impure superconducting lead. Domain structures in samples of pure lead were not reported. Recently, he has found large Faraday rotation for some paramagnetic glasses containing cerium metaphosphate, suggesting their use to study the structure of the intermediate state in superconductors.[2] By using the Faraday effect in glasses of similar nature, we have been able to resolve optically the domain structure in zone refined single crystal lead. "Frozen-in" flux in these specimens could also be observed. Differences in the structure of the intermediate state have been resolved in tantalum specimens of different metallurgical history, heat treatment, and cold work. The apparatus will be described, and preliminary observations on other superconductors presented.

[1] P. B. Alers, Phys. Rev. **105**, 104 (1957).
[2] P. B. Alers, Phys. Rev. (to be published).

**XA5. Nuclear Orientation of Cobalt-60 in Cerium Zinc Nitrate.*** M. W. LEVI, R. C. SAPP, AND J. W. CULVAHOUSE, *University of Kansas.*—Both alignment and polarization of cobalt-60 nuclei have been produced in a spherical single crystal of $Ce_2Zn_3(NO_3)_{12}\cdot 24H_2O$ cooled below 1°K by adiabatic demagnetization. The purpose was to study the influence of magnetic interactions between the cobalt and cerium ions upon the degree of nuclear orientation attained. Anisotropy of the gamma radiation pattern as high as 60% is produced by a magnetic field of 300 oe. In zero field the anisotropy is 26% at the lowest temperatures and passes through a maximum of 32% at higher temperatures. It is necessary to eliminate the effects of inhomogeneous warming of the sample in interpreting the data. The results show significant departures from theoretical curves computed using paramagnetic resonance parameters and crystal structure data, indicating the important effects of magnetic ordering in this salt on the nuclear orientation.

* Supported in part by the National Science Foundation and the Office of Naval Research.

**XA6. Kapitza Resistance.*** WILLIAM A. LITTLE, *Stanford University.*—Two calculations of the Kapitza resistance between a metal and liquid helium give a value considerably higher than the measured value. Khalatnikov's[1] calculation assumes that for the solid the surface modes of oscillation or epi-phonons are at the same temperature as the body modes or phonons. In the author's[2] earlier calculation the surface modes were neglected entirely. We show now that the epi-phonons are orthogonal to the phonon modes in the harmonic approximation. It is only the anharmonic terms in the Hamiltonian which couple the two modes together, and hence in the presence of a thermal gradient the epi-phonons will be at a temperature different, in general, from that of the phonons. If the anharmonic terms are strong enough to make Khalatnikov's assumption reasonable, an addition transfer of energy to the metal can occur from the surface disturbance which is generated by the totally reflected phonons from the helium. This gives a reduced Kapitza resistance and a different temperature and pressure dependence.

* Supported by the Office of Naval Research.
[1] I. M. Khalatnikov, Zhur. Exptl. i Teoret. Fiz. **22**, 687 (1952).
[2] W. A. Little, Can. J. Phys. **37**, 334 (1958).

**XA7. Isochores of Liquid Helium-4 near the λ Curve.*** O. V. LOUNASMAA,† *Argonne National Laboratory,* AND LEILA

KAUNISTO, *Wihuri Physical Laboratory.*—Accurate measurements of $(\partial p/\partial T)_V$ of liquid helium-4 have been made near the λ curve at various densities. The results indicate that $(\partial p/\partial T)_V<0$, not only in the He II region, but also in contrast with older measurements,[1] in the He I region near the λ curve; $(\partial p/\partial T)_V$ becomes positive 0.02°–0.06°K above the transition temperature. The isochores thus have a minimum in the He I region. These results are in agreement with the entropy diagram of Lounasmaa and Kojo,[2] who found that for He I close to the λ curve $(\partial S/\partial V)_T<0$. As $(\partial p/\partial T)_V$ changes very rapidly near the λ curve, it is difficult to determine how this derivative behaves at the transition point. The present results show, however, that the discontinuity in the values of $(\partial p/\partial T)_V$, if there is one, is much less spectacular than was suggested earlier. For studying the nature of the λ transition, measurements of $(\partial p/\partial T)_V$ are experimentally easier than those of the specific heat.

* Based on work performed, in part, under the auspices of the U. S. Atomic Energy Commission.
† On leave from the Wihuri Physical Laboratory, University of Turku, Turku, Finland.
[1] W. H. Keesom and A. P. Keesom, Physica 1, 128 (1933).
[2] O. V. Lounasmaa and E. Kojo, Ann. Acad. Sci. Fennicae **AVI**, No. 36 (1959).

**XA8. Behavior of Temperature Pulses in Dilute $He^3-He^4$ Solutions Near 0°K.*** D. J. SANDIFORD AND H. A. FAIRBANK, *Yale University.*—The velocity of propagation of temperature pulses in dilute solutions of $He^3$ in $He^4$ has been measured near 0°K. It is found that for solutions of less than about 0.5% concentration, and at temperatures below about 0.2°K, there are two velocities of propagation, differing in value by about a factor of 10. The effect occurs at higher temperatures as the pressure is increased, and also moves to higher temperatures as the concentration is reduced. The faster pulse has the characteristic shape and velocity of a heat pulse in pure $He^4$. The slower pulse has the velocity of second-sound expected in such mixtures.[1] It has been demonstrated that the effect is not explained by a phase separation, but is due to the simultaneous propagation of weakly coupled phonons and $He^3$ excitations.

* Supported by the National Science Foundation and the Office of Ordnance Research.
[1] I. Pomeranchuk, Zhur. Exptl. i Teoret. Fiz. 19, 42 (1949).

**XA9. Critical Heat Currents in Rotating Liquid Helium II.** C. E. CHASE, *Lincoln Laboratory,** *MIT.*—The effect of uniform rotation upon the critical heat current $W_c$ in liquid helium II has been studied. The apparatus consisted of a rectangular channel (0.041×0.109 cm) rotated about an axis normal to its length so that the heat flow was radical. One end of the channel was connected to a chamber containing a heater and resistance thermometer; the other end opened into the helium bath, where a second thermometer was located. $W_c$ was measured by a method proposed by Vinen.[1] As $\omega$ is increased, $W_c$ decreases in a series of steps, equally spaced in $\omega^{\frac{1}{2}}$. The angular velocities at these steps correspond to a linear separation of vortex lines of $1, \frac{1}{2}, \frac{1}{3}$ . . . times the channel width. This suggests that in a rotating channel only certain configurations of vertex lines are stable, and that the steps represent the appearance of additional groups or rows of lines.

* Operated by MIT with the support of the U. S. Army, Navy, and Air Force.
[1] W. F. Vinen, Proc. Roy. Soc. (London) **A240**, 128 (1957); **A243**, 400 (1957).

**XA10. Determination of the Angular Momentum of He II in a Rotating Cylinder.*** JOHN D. REPPY AND C. T. LANE, *Yale University.*—The free energy of a liquid in a rotating cylinder is minimized by solid body rotation with $\nabla\times v=2\omega$ where $v$ equals velocity and $\omega$ equals angular velocity of the cylinder. A basic condition on the superfluid velocity, $v_s$, is $\nabla\times v_s=0$. Several models have been advanced for rotating He II which satisfy this condition and give solid body values of the angular momentum for large $\omega$. However, at low speeds, there are significant deviations from the solid body values. We have measured the angular momentum of He II at 1.4°K for values of $\omega$ in the range 0.80 to 0.08 rad/sec. A cylindrical container, moment of inertia $I$, was filled with He II and suspended from a "frictionless" magnetic bearing then accelerated impulsively to an angular velocity, $\omega_0$. In the absence of further external torques, $\omega$ relaxes to a constant value, $\omega_f$. The angular momentum of the liquid is $L=(\omega_0-\omega_f)I$. Another determination of $L$ is made by radiant heating the liquid to above the λ point where it must rotate as a solid body. Any change in $L$ upon heating would be reflected as a change in $\omega$. Both of these methods yield solid body values for the angular momentum of the liquid even at the lowest speeds.

* Supported in part by the National Science Foundation and the Office of Ordnance Research, U. S. Army.

**XA11. Thermal Conductivity of Liquid Helium II.** J. W. HENDERSON, *Hughes Research Laboratories.*—A mode of thermal conductivity has been observed in liquid helium II in which the temperature gradient required to sustain a constant heat current is a linear function of the hydrostatic head of helium, and is nearly independent of the current density. This mode has been observed for relatively large heat currents. By contrast, the observed thermal conductivity at low heat currents is independent of the hydrostatic head of helium, and the thermal gradient is a function of the heat current and of the temperature, in general agreement with the mutual friction theory. At a given temperature, the transition from the latter to the former mode can be induced by either lowering the hydrostatic head of helium or by raising the current density. The transition is accompanied by a decrease in the observed temperature gradient. Just beyond transition currents, the first mode occurs intermittently, causing an oscillation in the observed temperature gradients. The temperature dependence of these effects has been determined in the 1.5°K to 2.2°K range.

**XA12. Nuclear Quadrupole Moments and Superfluidity.*** N. K. GLENDENNING AND J. SAWICKI, *Lawrence Radiation Laboratory, Berkeley.*—The theory of superfluidity of Bardeen, Cooper, and Schrieffer allows the calculation of properties of a many-fermion system interacting through a pairing force. The theory has been applied to nuclei by several authors. As an additional test of the applicability of this theory to nuclei, we have calculated the intrinsic quadrupole moments of even-$Z$ nuclei. We computed the single-particle density matrix $\rho$, corresponding to a quadrupole deformation of the spherical shell model, following the work of Migdal.[1] The quadrupole moment is then $Q_0=Tr(\rho Q)$ where $Q$ is the single-particle quadrupole moment evaluated in the shell-model states. The quantity that we calculate in this manner is $Q_0/\delta$, and we compare it with the result customarily used in analyzing quadrupole moments; the uniformly charged spheroid moment $Q_0/\delta=(4/5)ZR^2$. Our calculations exhibit two features: (1) In the absence of the pairing force, $Q_0/\delta$ displays a strong shell closure effect. (2) The pairing force has the effect of smoothing out the shell fluctuations, and confirms the approximate validity of the uniformly charged spheroid result. For large deformations we are treating the deformation through the use of Nilsson's eigenfunctions for the basic states.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] A. B. Migdal, Nuclear Phys. 13, 655 (1959).

THURSDAY MORNING AT 9:30

Burgundy Room

(S. A. KORFF presiding)

### *Invited Papers in Cosmic-Ray and Space Physics*

**XB1. Primary Cosmic Variation over Half a Solar Cycle.** F. M. MCDONALD, *Goddard Space Flight Centre.* (30 min.)

**XB2. Magnetic-Field Studies on Vanguard III.** J. P. HEPPNER, *Goddard Space Flight Centre.* (30 min.)

**XB3. Protons and Tritons Trapped in the Inner Radiation Belt.** R. S. WHITE, *University of California, Livermore.* (30 min.)

**XB4. Cosmic Rays from Hydrodynamic Effect and Supernovae.** S. A. COLGATE, *University of California, Livermore.* (30 min.)

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THURSDAY MORNING AT 9:00

Sheraton Hall

(V. F. WEISSKOPF presiding)

### *Invited Papers*

**Y1. Some Recent Developments in the Theory of Nuclear Structure.** AAGE BOHR, *Institute for Theoretical Physics, Copenhagen.* (45 min.)

**Y2. Recent Developments at CERN.** C. J. BAKKER, *CERN.* (45 min.)

**Y3.** Title and speaker to be announced.

**Y4.** Title and speaker to be announced.

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THURSDAY MORNING AT 9:30

Adams-Hamilton Room

(GREGORY BREIT presiding)

### *Nuclear Interactions VI*

**YA1. Nuclear Reaction Products from the Lithium Bombardment of $Li^7$ and $Li^6$ Targets.*** G. C. MORRISON AND M. N. HUBERMAN, *University of Chicago* (introduced by S. K. Allison).—Angular distributions of the emergent protons, deuterons and tritons from the lithium induced reactions in $Li^6$ and $Li^7$ targets leading to discrete states in the final nuclei are being studied for an incident lithium energy of 2 Mev. Identification of the outgoing particles is achieved with a proportional counter CsI(Tl) scintillation counter telescope system, which gives a measure of the "$dE/dx$" and $E$ of the emitted particles. In the reaction $Li^7(Li,d)B^{11}$ preliminary angular distributions have been obtained for the deuterons leading to the ground state and first excited states of $B^{11}$. Deuterons leading to the ground and third excited states show a forward peaking, whereas those leading to the first and second excited states have a comparatively flat distribution. In the reaction $Li^7(Li^7,t)B^{11}$, tritons leading to the ground state of $B^{11}$ show a similar forward peaking. Further measurements on the angular distributions of the deuteron and triton groups from the above reactions and also the proton groups from the reaction $Li^6(Li^6,p)B^{11}$ are in progress.

* This research supported in part by a grant from the U. S. Atomic Energy Commission.

**YA2. Disintegration of $Li^6$ in Collisions with Gold Nuclei.*** CARL E. ANDERSON, WILLIAM J. KNOX, AND ARTHUR R. QUINTON, *Yale University.*—A process similar to the disintegration of a deuteron into a proton and a neutron has been observed by bombarding a gold target with $Li^6$ ions. The disintegration products observed are alpha particles, deuterons and protons. Neutrons would not be detected by the apparatus used. Observations have been made at $Li^6$ bombarding energies of 60, 34, and 25 Mev. The total cross sections for alpha particles are approximately 500, 400, and 40 mb, respectively. At 60-Mev bombarding energy the angular distributions of alpha particles peaks at about 25°. The alpha-particle energy distribution peaks at 40 Mev and has full width at half-maximum of about 14 Mev. These results are inconsistent with the predictions of compound nucleus evaporation theory. The results are more in accord with an interpretation based upon a combination of two mechanisms, (1) Coulomb excitation of $Li^6$ to unbound levels with subsequent disintegration and (2) nuclear stripping.[1]

* Supported by the U. S. Atomic Energy Commission.

[1] G. Breit, R. Gluckstern, J. McIntosh, M. el Nadi, and G. Rawitscher (private communication).

**YA3. Excitation of Nuclei in Neutron Transfer Reactions.*** T. L. WATTS, F. C. JOBES, AND J. A. MCINTYRE, *Yale University.*—The ranges of $N^{13}$ nuclei produced by the neutron transfer reaction $Au^{197}(N^{14},N^{13})Au^{198}$ have been measured in

aluminum. Data were taken for various bombarding energies at scattering angles corresponding to the peaks of the angular distributions. At the bombarding energy of 130 Mev, the energy[1] of the $N^{13}$ nuclei varied over a range of approximately 20 Mev, an asymmetric spectrum being obtained. The peak of the spectrum was some 6 Mev below that of the longest range $N^{13}$ nuclei, and was near to the energy corresponding to neutron transfers to low-energy continuum states of the $Au^{198}$ nucleus. At a bombarding energy of 85 Mev, the energy of the $N^{13}$ nuclei varied by approximately 12 Mev and a more symmetric energy spectrum was found. Again the peak appeared at an energy near to that corresponding to neutron transfers to low-energy continuum states.

* Supported by U. S. Atomic Energy Commission.
[1] L. C. Northcliffe (private communication).

**YA4. Universal Curves for Neutron Transfer ($N^{14}$,$N^{13}$) Reactions.*** G. HERLING, Y. NISHIDA, AND G. BREIT, *Yale University.*—The universal curves for nucleon transfer ($N^{14}$,$N^{13}$) reactions[1] have been studied in the two approximations discussed by Breit.[2] Only the simplified form has been used in the literature so far. Marked changes in relative positions of lines caused by using the primary form occur for $S^{32}$ which agrees more closely with $Mg^{24,25}$, $Be^{9}$ which falls more nearly on the same line with $C^{12}$ and $O^{16}$, and $B^{10}$ which falls more strongly outside the other groups. Limitations on conclusions caused by neutron binding energies in initial and final states will be discussed.

* Supported by Office of Ordnance Research, U. S. Army and by U. S. Atomic Energy Commission.
[1] M. L. Halbert, T. H. Handley, J. J. Pinajian, W. H. Webb, and A. Zucker, Phys. Rev. 106, 251 (1957); D. E. Fischer, A. Zucker, and A. Gropp, Phys. Rev. 113, 542 (1959).
[2] G. Breit, *Handbuch der Physik* (Springer-Verlag, Berlin, Germany, 1959), Vol. 41, pp. 389, 399.

**YA5. Elastic Scattering of Carbon on Carbon.** D. A. BROMLEY, J. A. KUEHNER, AND E. ALMQVIST, *Chalk River Laboratories.*—A detailed study of the elastic scattering of carbon on carbon has been carried out with carbon ions from the tandem accelerator in the energy range from 6 to 29 Mev. Use of room temperature, Au-Si surface barrier detectors, and thin targets ($\sim$10 $\mu g/cm^2$) results in a system energy resolution $\lesssim$2% and permits the exclusion of contributions from elastic scattering on target contaminants and from inelastic scattering without necessitating coincidence measurements. Differential excitation functions have been measured at $\phi_{c.m.}=90°$, 60°, and 39°; angular distributions have been measured for $10°\lesssim\phi_{c.m.}\lesssim120°$ at 6.0, 10.0, 20.0, 22.5, 25.0, and 26.7 Mev. At energies below 13 Mev, Mott scattering predictions are in quantitative agreement with the data. At higher energies, pronounced resonant structure appears in the 90° and 60° excitation curves corresponding to excitations $\gtrsim$20 Mev in the compound system $Mg^{24}$. Although the average cross section drops below the Rutherford prediction, it does not show the rapid exponential decrease characteristic of previous deuteron, alpha, and heavy ion studies and, in particular, of the $O^{16}$+$O^{16}$ data reported in the following abstract. It has not been found possible to obtain quantitative fits to the angular distribution data using a sharp cutoff Blair model; qualitative agreement suggests that the observed resonant structure reflects selective absorption of particular orbital momenta from the incident wave.

**YA6 Elastic Scattering of Oxygen on Oxygen.** E. ALMQVIST, D. A. BROMLEY, AND J. A. KUEHNER, *Chalk River Laboratories.*—The elastic scattering of oxygen on oxygen has been studied in the laboratory energy range from 6 to 32 Mev using Au-Si surface barrier detectors, thin SiO targets, and the oxygen beam from the tandem accelerator. Excitation functions in this energy range for the elastic scattering have been measured at $\phi_{c.m.}=90°$, 60°, and 39°; angular distributions have been measured for $10°\lesssim\phi_{c.m.}\lesssim120°$ at incident energies of 14.0, 17.6, 20.9, 26.0, and 30.0 Mev. For incident energies less than 23 Mev, Mott scattering formalism gives quantitative agreement with the experimental data; above this energy, the cross section at $\phi_{c.m.}=90°$ decreases approximately exponentially with energy giving the 'break' behavior characteristic of previously reported deuteron, alpha, and heavy ion scattering.[1] This is in marked contrast to the situation reported in the preceding abstract for $C^{12}$+$C^{12}$. The data will be compared with the results of calculations by using both the Blair sharp cutoff model and a standard optical model.

[1] D. D. Kerlee, J. S. Blair, and G. W. Farwell, Phys. Rev. 107, 1343 (1957); A. Zucker and M. L. Halbert, Bull. Am. Phys. Soc. Ser. II, 5, 67 (1960).

**YA7. Elastic Scattering: $O^{16}$ on C, Mg, Al, and Si and $C^{12}$ on O and Si.** J. A. KUEHNER, E. ALMQVIST, AND D. A. BROMLEY, *Chalk River Laboratories.*—Elastic scattering of $O^{16}$ ions has been studied on thin targets of C, Mg, Al, and SiO. Excitation functions for the C+O scattering have been measured in the center of mass energy range from 3.5 to 16 Mev at $\phi_{c.m.}=90°$, 63°, and 33°; angular distributions have been measured for $6°\lesssim\phi_{c.m.}\lesssim120°$ for incident $O^{16}$ ion energies of 10.0, 27.0, and 31.9 Mev, and for incident $C^{12}$ ion energies of 7.5, 23.9, and 26.7 Mev. The angular distributions at higher energies show the characteristic break phenomenon[1]; pronounced diffractionlike oscillations are superposed on the exponential decrease.[2] Elastic scattering data for $O^{16}$ and $C^{12}$ on Si were obtained simultaneously with the above measurements, using SiO targets. The angular distributions are very similar to those measured for 31.9 Mev $O^{16}$ ions on Mg and Al targets, showing the usual exponential decrease below the Rutherford predictions at larger angles. The experimental apparatus has been checked by observing that the scattering of 27 Mev $O^{16}$ ions on Au follows the Rutherford predictions in the range $2°\lesssim\phi_{c.m.}\lesssim120°$. These data will be interpreted to give information on the interaction radii. Optical model and sharp cutoff model analyses will be presented.

[1] A. Almquist, D. A. Bromley, and J. A. Kuehner, Bull. Am. Phys. Soc. Ser. II, 5, 293 (1960), preceding abstract.
[2] M. L. Halbert and A. Zucker, Phys. Rev. 115, 1635 (1959).

**YA8. Coulomb Excitation after Using $O^{16}$ Ions.** H. E. GOVE AND C. BROUDE, *Chalk River Laboratories.*—$O^{16}$ ions in the energy range from 12 to 36 Mev from the Chalk River tandem accelerator have been used to Coulomb excite a number of elements ranging from sodium to nickel. In all cases, the thick target yield was measured over as wide a range of incident oxygen ion energy as possible. The levels investigated were the 0.43-Mev level in $Na^{23}$, the 1.37-Mev level in $Mg^{24}$, the 0.84- and 1.01-Mev levels in $Al^{27}$, the 1.78-Mev level in $Si^{28}$, all in the1*d* shell. In the medium weight elements, the levels at 0.32 and 0.93 Mev in $V^{51}$, 0.98 Mev in $Mn^{55}$, 0.845 Mev in $Fe^{56}$, 1.45 Mev in $Ni^{58}$, and 1.33 Mev in $Ni^{60}$ were measured. Of these, Coulomb excitation of the levels in $Si^{28}$, $V^{51}$ (0.93 Mev), $Mn^{55}$, and the two nickel isotopes have not previously been reported. The results for $Mg^{24}$ and $Al^{27}$ are in reasonable agreement with previous measurements.[1] The results for the 1.78 Mev level in $Si^{28}$, which is the highest excitation energy yet reached by Coulomb excitation give a value of $B(E2)$ for excitation of 0.025 $\pm0.006e^2\times10^{-48}$ $cm^4$. This corresponds to an enhancement factor of $10\pm3$ relative to the single-particle value. It is interesting to note that this is about half that for the 1.37-Mev level in $Mg^{24}$. Values of $B(E2)$ for the medium weight elements will be presented.

[1] D. G. Alkhazov, A. P. Grinberg, G. M. Gusinskii, K. I. Erokhina, and I. Kh. Lemberg, Soviet Phys.—JETP 35, 736 (1959).

**YA9. Evaporation of Neutrons from a Highly Excited Compound System.*** H. W. BROEK, WILLIAM J. KNOX, AND

CARL E. ANDERSON, *Yale University.*—Neutrons emitted in the 160-Mev oxygen ion bombardment of nickel have been observed. A single stilbene crystal was used as a fast neutron detector.[1] Energy and angular distributions have been measured for neutrons from 6 to 12 Mev in the c.m. system. The energy spectra can be fitted by Maxwellian distributions with nuclear temperatures of approximately 2.5 Mev. The c.m. angular distribution is symmetric about 90° and peaked in the forward and backward directions. This shape is attributed to the high angular momentum of the compound system. This effect has previously been observed in the angular distribution of charged particles emitted in the same reaction.[2] The energy spectra decrease with energy more rapidly than does the evaporation spectrum calculated for this reaction by Dostrovsky, Friedlander, and Fraenkel.

* Work supported by the U. S. Atomic Energy Commission.
† National Science Foundation Cooperative Graduate Fellow 1959–1960.
[1] H. W. Broek and C. E. Anderson, Bull. Am. Phys. Soc. II, **5**, 33 (1950).
[2] W. J. Knox, A. R. Quinton, and C. E. Anderson, Bull. Am. Phys. Soc. Ser. II, **4**, 51 (1959).

**YA10. Asymmetric Fission of Bismuth.*** T. T. SUGIHARA AND J. ROESMER, *Clark University.*—The fission mass distribution of bismuth with 22-Mev deuterons has been shown by Fairhall[1] to be symmetric, unlike that of uranium and other heavy fissile nuclei. Radium exhibits both symmetric and asymmetric fission modes with 11-Mev protons.[2] Careful examination of low-yield products in the mass region 66 to 77 indicates that bismuth undergoes asymmetric fission with 36-Mev protons, but with very low probability. The fission cross section is 2.3 mb, only about 0.3% of which results in asymmetric mass division. With 58-Mev protons the fission cross section is 14 mb and no evidence for asymmetric fission was observed. These results will be compared with the Fairhall model for fission.

* Supported in part by U. S. Atomic Energy Commission.
[1] A. W. Fairhall, Phys. Rev. **102**, 1335 (1956).
[2] R. C. Jensen and A. W. Fairhall, Phys. Rev. **109**, 942 (1958).

**YA11. Anomalous Parameters of the 0.2 ev Resonance in $U^{233}$ Slow Neutron Induced Fission.*** M. S. MOORE AND C. W. REICH, *Phillips Petroleum Company.*—A multilevel analysis[1] of the slow neutron total and fission cross sections of $U^{233}$ has indicated that the small resonance near 0.2 ev has a vanishingly small neutron width. Such a resonance would be completely unobservable if there were no interference among resonances in fission. Further studies have shown that adequate fits to the fission and total cross sections can be obtained by assuming the neutron width of this resonance to be identically zero. Even in this case, an appreciable radiative capture component exists, showing that the single level Breit-Wigner formula is not adequate to describe radiative capture in the presence of fission.

* Work done under the auspices of U. S. Atomic Energy Commission.
[1] M. S. Moore and C. W. Reich, Phys. Rev. (to be published).

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## THURSDAY MORNING AT 9:30

## Adams-Hamilton Room

## (L. B. BORST presiding)

## *Neutron Physics II*

**Z1. Resonant Neutron Scattering in $Pu^{239}$.** J. S. FRASER* AND R. B. SCHWARTZ,† *A.E.R.E., Harwell.*—The Harwell 28 Mev linear electron accelerator has been used to study the neutron scattering from a thin sample ($5\times10^{19}$ atoms/cm$^2$) of $Pu^{239}$, in order to determine the spins of the low-lying resonances. An annular detector consisting of eighteen $B^{10}F_3$ proportional counters surrounded the sample, 15 m from the enriched uranium "booster" target of the accelerator. The contribution of fission neutrons was determined by filtering out the scattered neutrons with a $B_4C$ annulus. Values of $\sigma_0\Gamma_n$ were determined by an area analysis of the net scattered neutron yield.[1] The measured values of $\sigma_0\Gamma_n$ for the 7.8, 10.9, and 11.9 ev resonances are $2.1\pm0.6$, $3.6\pm0.9$, and $3.0\pm0.6$ ev-barns, respectively. If we combine these scattering results with total cross section measurements previously reported,[2] we obtain values for $g$, the statistical weight factor, of $0.78\pm0.23$, $0.68\pm0.18$, and $0.80\pm0.17$, respectively. Spin $J=1$ is therefore assigned to each of these three levels.

* Present address: Atomic Energy of Canada Limited, Chalk River, Ontario.
† Now at Brookhaven National Laboratory, Upton, New York.
[1] E. R. Rae *et al.*, Nuclear Physics **5**, 89 (1958).
[2] Bollinger, Coté, and Thomas, *Proceedings of Second International Conference on Peaceful Uses of Atomic Energy* **15**, 127 (1958).

**Z2. Determination of Spins of Neutron Resonances from Coincident $\gamma$-Ray Spectra.*** L. M. BOLLINGER AND R. E. COTÉ, *Argonne National Laboratory.*—Many experimenters have used high-energy spectra of single $\gamma$ rays from resonant capture of neutrons in even-odd $\frac{1}{2}^-$ target nuclides to determine the character of the compound state formed.[1] A new method best suited to even-odd $\frac{1}{2}^+$ target nuclides is described. One observes coincident counts in two NaI scintillators and records the spectrum of the sum of the two pulse heights. Sum pulses equal to the binding energy are usually formed by two electric dipole transitions linking the $0^+$ or $1^+$ initial and the $0^+$ final states. Elementary considerations indicate that the probability of such transitions is 3 times as great for $0^+$ as for $1^+$ initial states. The fluctuations in the ratio 3 should be small, since many modes of decay form sum pulses of full energy. Similarly, the ratio of intensities of sum transitions to the ground state and to the $2^+$ first excited state is roughly 1 for $0^+$ initial states and $\frac{1}{3}$ for $1^+$ initial states. Preliminary results for $Cd^{113}$ are consistent with these speculations and indicate an assignment of spin 1 for the resonances at 0.178, 18, 64, and 108 ev. Similar experiments will be attempted on other classes of target nuclides.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. H. Landon and E. R. Rae, Phys. Rev. **107**, 1333 (1957).

**Z3. Neutron Resonance Spin States in $Eu^{151}$.** A. STOLOVY, *U. S. Naval Research Laboratory.*—By observing the interaction of a polarized neutron beam with a polarized target of europium metal, the spin states of resonances in $Eu^{151}$ are being investigated. The target polarization is produced by applying a strong magnetic field to the sample when its temperature is brought to a few hundreds of a degree absolute.[1] The neutron beam polarization is produced by a spectrometer utilizing a magnetized cobalt-iron crystal, and the beam orientation in flight can be controlled by current-carrying copper bars. The spin states associated with the 0.327- and 0.461-ev resonances have been found to be $J=3$ and 2,

respectively. These levels are known to have different radiation widths[2] and isomeric activation ratios.[3] As in our previous work on indium,[4] the decay properties of these levels seem to be strongly influenced by the level spin. Work is in progress on other resonances in europium.

[1] J. W. T. Dabbs, L. D. Roberts, and S. Bernstein, Phys. Rev. 98, 1512 (1955).
[2] H. H. Landon and V. L. Sailor, Phys. Rev. 98, 1267 (1955).
[3] R. E. Wood, Phys. Rev. 95, 453 (1954).
[4] A. Stolovy, Phys. Rev. (to be published).

**Z4. Low-Energy Gamma Rays from Resonance Neutron Capture in $In^{115}$.** RICHARD H. VOGT, *U. S. Naval Research Laboratory.*—The relative intensities of low-energy gamma rays from resonance neutron capture in $In^{115}$ at 1.46, 3.86, and 9.10 ev were compared in an attempt to relate the spectra to the two possible spin states of the compound nucleus.[1] The cases examined appear to fall into two classes of spectra in agreement with the results of the polarization measurements of A. Stolovy[2] which assign a spin of 5 to the 1.46- and 9.10-ev resonances, and a spin of 4 to the 3.86-ev resonance. The results differ from those of Draper *et al.*[1] in the relative intensities of the gamma ray at 63 kev.

[1] J. E. Draper, C. A. Fenstermacher, and H. L. Schultz, Phys. Rev. 111, 906 (1958).
[2] A. Stolovy (to be published).

**Z5. Neutron Strength Function and Resonance Parameters of Ruthenium.*** H. H. BOLOTIN AND R. E. CHRIEN, *Brookhaven National Laboratory.*—The BNL fast chopper and 1024 time-of-flight analyzer have been used to investigate the neutron transmission of Ruthenium. Samples of normal Ru and those enriched in $Ru^{100}$ and $Ru^{101}$ were used. In the energy region up to approximately 200 ev, ten levels were observed of which six have not been reported previously. Neutron widths and isotopic identification of these levels will be presented. A least-squares analysis of the area under the transmission dips, using a wide range of sample thicknesses, has been used to determine the total radiation widths of several of these levels. The region of atomic weight, $90<A<130$, is highly interesting with regard to the characteristics of $s$-wave neutron interactions, for it is here that measurements of $s$-wave strength functions differ most from optical model predictions.[1] We have determined the $s$-wave strength function of normal Ru ($A=101$) from the average cross section in the kv region. This result will be presented and compared with previous measurements on neighboring nuclei.[1]

* Work carried out at Brookhaven under the auspices of the U. S. Atomic Energy Commission.
[1] D. J. Hughes, R. L. Zimmerman, and R. E. Chrien, Phys. Rev. Letters, 1, 461 (1958).

**Z6. I. Area Analysis of Neutron Resonances.*** J. L. ROSEN, *Columbia University.*—The technique of area analysis of neutron resonance transmission data has been extended to include the effects of both significant potential scattering interference and Doppler broadening. Numerical calculations of the area function have been made. The three independent variables, namely, the peak cross-section times sample thickness $n\sigma_0$, the potential factor $R/\lambda$ and the Doppler broadening parameter $\Delta/\Gamma$, were varied over the following ranges: $0.125\leq n\sigma_0\Gamma/\Delta\leq 90.5$, $0.25<\Delta/\Gamma\leq 16$, and $0\leq R/\lambda\leq 0.565$. The method of analysis will be illustrated using thorium transmission data. The inclusion of first-order high energy and many-level corrections will be discussed.

* This work partially supported by the U. S. Atomic Energy Commission.

**Z7. II. Neutron Resonances in Th, I, and Br.*** S. DESJARDINS, W. W. HAVENS, JR., J. RAINWATER, AND J. L. ROSEN, *Columbia University.*—The Columbia University Nevis Velocity Selector has been used to measure 60 Th resonances up to 1200 ev, 61 I resonances up to 815 ev, and 37 Br (natural) resonances up to 1000 ev. The I and Br data were obtained by the capture $\gamma$-ray self-indication scheme, while a $B^{10}$–NaI flat detector was employed for the transmission measurement of Th. The latter detector provides reasonably high efficiency, good $\gamma$-background rejection, and a dead time of $<0.5$ $\mu$sec. It has permitted data recording rates of $\sim$20 counts per neutron burst into 2000 channels of 0.1 $\mu$sec width. Some of the features of the system will be noted. Strength functions and neutron widths will be presented. Radiation widths and, in the case of Br, $J$ values as well, have been inferred for several favorable levels.

* This work partially supported by the U. S. Atomic Energy Commission.

**Z8. Temperature Dependence of Resonant Shapes for Neutron Capture.*** H. E. JACKSON, L. M. BOLLINGER, AND R. E. COTÉ, *Argonne National Laboratory.*—In view of the recent interest in the effect of crystalline binding as observed in the resonant absorption of $\gamma$ rays, an effort was made to observe the analogous effect for resonant capture of neutrons. As predicted by Lamb,[1] crystalline binding is expected to result in resonances having distorted shapes. In an effort to observe this effect, the 6.7-ev resonance in $U^{238}$ and the 6.6-ev resonance in osmium are being examined at several temperatures. To date, transmission measurements have been made with the samples at temperatures of 297°K and 105°K with the Argonne fast chopper. Analyses of the data by a curve-fitting procedure indicate that the shapes of the resonances are consistent with those expected if the thermal motions in the target are distributed as in a gas. This result agrees with calculations based on Lamb's crystal model of thermal motions, which indicates that effects of lattice binding would be too small to be observed at the above temperatures. For this reason, measurements are planned at much lower temperatures.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. E. Lamb, Jr., Phys. Rev. 55, 190 (1939).

**Z9. Distribution of the Angular Momenta, Level Spacings, and Neutron Widths of $Na^{24}$.*** CARL T. HIBDON, *Argonne National Laboratory.*—A plot of the ratio of the level densities (normalized to $J=1$) vs $J$ agrees with the distribution given for the single-particle model by the expression[1]

$$\rho(U,J)=\rho(U)\{\exp[-J^2/2\sigma^2]-\exp[-(J+1)^2/2\sigma^2]\} \quad (1)$$

for a value of $\sigma=1.8$. The quantity $\sigma$ is a constant times the nuclear temperature and $\rho(U)$ is the density of all levels for the energy interval in question. The reduced widths $\gamma_i^2=\Gamma_n/(2P_i)$ fluctuate rather violently among these levels but appear to agree fairly well with the distribution $120\exp(-x)$ or the Porter-Thomas distribution $60x^4\exp(-x/2)$, where $x=\gamma^2/\langle\gamma^2\rangle_{av}$ is evaluated for a particular $J$ and parity. The level spacings appear to agree with the distribution $100\exp(-s)$ but do not agree with the Wigner surmise, $\pi(s/2)\exp(-\pi s^2/4)$, where $s=S/D$ with $S$ the level spacing and $D$ the average level spacing for a particular $J$ and parity. These distributions cover the neutron resonance levels up to 630 kev. The value of the strength function $\langle\gamma^2\rangle_{av}/D$ for $l=0$ is 0.045 and for $l=1$ it is 0.37.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. Bloch, Phys. Rev. 93, 1094 (1954).

**Z10. Transition Probabilities of Capture Gamma Rays in $U^{239}$.*** D. J. HUGHES, H. PALEVSKY, R. E. CHRIEN, AND H. H. BOLOTIN *Brookhaven National Laboratory.*—There has been much speculation recently in the question of transition probabilities of high-energy gamma rays from neighboring states excited by capture of neutrons in specific resonances. It was expected that these transition probabilities would fluctuate widely from level to level, corresponding to a single-channel

process for radiation to the same final state. However, measurements of ground state transitions have revealed much smaller fluctuations than expected for a one-channel distribution. The smallest fluctuations have been observed for the target nucleus $U^{238}$ in which the 4.06-Mev gamma was studied.[1] Although this gamma ray is not a ground state transition, it is a prominent transition and well suited for the study of fluctuations. Because of the importance of the small fluctuations observed in transitions from the levels of $U^{239}$ the investigations have been continued, with special emphasis on any effects that might give a spurious constancy to the radiation strength. Measurements with a single NaI crystal have now been compared with six crystal measurements to study the resolving power and the possibility of counting of multiple gamma rays with the multiple crystals.

* Research carried out at Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission.

[1] M. K. Brussel, D. J. Hughes, and R. L. Zimmerman, Bull. Am. Phys. Soc. Ser. II, 5, 32 (1960).

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## THURSDAY MORNING AT 9:30

National Bureau of Standards, Materials Testing Laboratory

(L. R. MAXWELL presiding)

### *Magnetism*

**ZA1. Machine Computation of a Two-Dimensional Ising Lattice.*** C. P. YANG, *The Johns Hopkins University* (introduced by T. H. Berlin).—The computation consists in generating by a digital computor a sequence of configurations for a $10\times10$ Ising lattice with periodic boundary conditions. The various quantities of interest such as the average energy, the specific heat, etc., are then calculated from the ensemble, which is generated in such a way that each configuration would occur with a relative probability approximately proportional to the Boltzmann factor. Two proofs of this fact will be given. The computation time with an IBM 704 is a few minutes. Comparisons with Onsager's exact results are favorable.

* Supported by the National Science Foundation.

**ZA2. Time-Dependent Statistics of an Ising Chain.*** ROY J. GLAUBER, *Harvard University.*—The state of a closed $N$-site Ising chain is described by a set of two-valued spin variables, $\sigma_j=\pm1$, $(j=1\cdots N)$. We assume that the spins, in the absence of coupling between them, interact independently with an external agency (e.g., a heat reservoir) which causes the $\sigma_j$ to vary as random functions of time. All of the spins, when uncoupled, are assumed to have the same probability per unit time for undergoing transitions to the unoccupied state. Coupling between the spins is introduced by assuming that the probability per unit time that any spin flips is influenced by the spin states of its neighbors relative to its own. The set of $2^N$ probability functions for the various states of the system obeys a set of (coupled) differential equations characteristic of a continuous Markoff process. The expectation values of the spins $\langle\sigma_j(t)\rangle$ and of their bilinear products $\langle\sigma_i(t)\sigma_j(t)\rangle$ satisfy reduced systems of equations which may be solved explicitly for the case of nearest-neighbor coupling. The solutions relax at large times into those of the familiar Ising model at equilibrium. We also secure an evaluation of the time-dependent correlation function $\langle\sigma_i(t)\sigma_j(t')\rangle$ for an arbitrary pair of spins.

* Supported in part by the U. S. Air Force Office of Scientific Research.

**ZA3. Energy, Specific Heat, and Magnetic Property of the Low-Density Electron Gas.** W. J. CARR, JR., *Westinghouse Research Laboratories.*—A series expansion in powers of $r_s^{-1}$ has been obtained for the ground state energy of a dilute electron gas, the result being, in rydberg units per particle, $E=-1.792/r_s+2.66/r_s^{\frac{3}{2}}+b/r_s^2+0\ (1/r_s^{5/2})+$terms falling off exponentially with $r_s^{\frac{1}{2}}$. The dimensionless parameter $r_s$ is the radius of the unit sphere in Bohr radii. The term in $r_s^{-1}$ is the energy of a body-centered-cubic lattice of electrons as calculated by Fuchs; the $r_s^{-\frac{3}{2}}$ term is the zero-point vibrational energy of the lattice, for which the normal modes have been calculated; and $br_s^{-2}$ is the first-order effect of anharmonicities in the vibration. The constant $b$ has been estimated, its magnitude being small compared with unity. A first-order approximation has been obtained for the exponential terms in the energy. Part of this energy comes from exchange, which leads to the result that for electron densities of physical interest the electron spins are antiferromagnetically alined. An order of magnitude for the Néel temperature has been calculated.

**ZA4. Paramagnetic Susceptibility of Sodium Metal at 4°K.*** R. T. SCHUMACHER AND W. E. VEHSE, *Carnegie Institute of Technology.*—We have measured the paramagnetic ("Pauli") susceptibility of the conduction electrons in sodium metal at 4.20°K. The technique, identical to one previously used,[1] involves comparing the intensity of the nuclear magnetic resonance to the electron spin magnetic resonance in the same sample and apparatus. The result, in cgs volume units, is $\chi_P=(0.89\pm0.04)\times10^{-6}$. This value is in essential agreement with the previous, less precise result,[1] which was measured at 77°K. The measurement is not yet precise enough to determine whether or not the Knight shift anomaly[2] is due to a temperature-dependent susceptibility. Although the total susceptibility of sodium has not been measured at 4°K, one may still infer from room-temperature measurements, combined with the present result, that the conduction electron diamagnetic susceptibility is anomalously small.

* Supported in part by the National Science Foundation.

[1] R. T. Schumacher and C. P. Slichter, Phys. Rev. 101, 58 (1955).

[2] D. W. Feldman (private communication). See W. D. Knight, *Solid State Physics* (Academic Press, Inc., New York), Vol. 2, p. 128.

**ZA5. Magnetic Susceptibilities of $Cu(HCO_2)_2\cdot4H_2O$ and $Cu(HCO_2)_2\cdot2H_2O$ at Low Temperatures.*** R. B. FLIPPEN AND S. A. FRIEDBERG, *Carnegie Institute of Technology.*—The magnetic susceptibility of $Cu(HCO_2)_2\cdot4H_2O$ in powdered and single-crystal form has been measured in the liquid hydrogen and helium temperature regions by an ac mutual inductance bridge method. The powder susceptibility of $Cu(HCO_2)_2\cdot2H_2O$ has been similarly determined. $\chi_{powder}$ of $Cu(HCO_2)_2\cdot2H_2O$ follows a Curie-Weiss law from 20.2° to 14.0°K, but rises faster than as $T^{-1}$ from 4.2° to 1.3°K. $\chi_{powder}$ of $Cu(HCO_2)_2\cdot4H_2O$ exhibits a strong peak suggestive of a magnetic phase transition at 16.8°K. It then falls to two-thirds the peak value at 4.2°K and is constant below this temperature. $Cu(HCO_2)_2$

$\cdot 4H_2O$ is monoclinic, and susceptibilities measured along the three crystal axes show large anisotropy. $\chi_a$ rises to a sharp peak at 16.8°K, then falls to about the powder value at 4.2°K. $\chi_c$ also exhibits a maximum at 16.8°K, but assumes a nearly constant value only slightly below that temperature. $\chi_b$ is much smaller than $\chi_a$ or $\chi_c$, and is nearly temperature independent below 20.2°K. All three susceptibilities are thus constant below 4.2°K with molar values $\chi_b = 0.0040$, $\chi_a = 0.0182$, $\chi_c = 0.0269$. Applied magnetic fields up to 1000 gauss had no effect on the susceptibilities. The relation of these results to the $\chi_{powder}$ values of Martin and Waterman[1] above 90°K will be discussed.

* Work supported by the Office of Naval Research, The National Science Foundation, and Alfred P. Sloan Foundation.
[1] R. L. Martin and H. Waterman, J. Chem. Soc., 1359 (1959).

**ZA6. Magnetic Properties of Small Crystals.*** D. A. GREENWOOD,† R. BROUT, AND J. A. KRUMHANSL, *Cornell University.*—The magnetic properties of small metallic crystals with linear dimensions ~100 A has been investigated. The spacing of one-electron levels in such crystals, at the Fermi surface, is about $10^{-4}$ ev, whereas the splitting $\mu$H is about $10^{-5}$ ev in a field of 1 kgauss. Hence, in such small crystals the spin paramagnetism vanishes at low temperatures ($kT \lesssim 1$°K) if the number of conduction electrons is even. The effect of a single unpaired electron has been calculated, and found to be appreciable. Thus, in general, a Knight shift experiment on uniform small crystals might be expected to show two peaks.

* This work was supported by the U. S. Atomic Energy Commission.
† On leave of absence from Birkbeck College, University of London.

**ZA7. Effective Magnetic Field at the Nucleus in Magnetic Materials.** C. V. HEER, *Ohio State University.*—The available data on the effective magnetic field at the nucleus which were determined from $\gamma$-ray emission, specific heat, and resonance data for magnetic materials with an unfilled 3-*d* band are found to be approximately given by the expression: $B_{nucleus} = 125\ \mu_{eff}$ kgauss. The value of $\mu_{eff}$ is taken from the Slater-Pauling curve for atomic moment as a function of the number of 3-*d* electrons. This trend is discussed in terms of an elementary band theory of magnetism. The effective field at the nucleus is assumed due to a contact interaction with the inner *s*-band electrons, whose radial wave functions are perturbed by an amount proportional to the effective spin moment of the electrons in the 3-*d* band. Detailed calculations for a perturbation of this type for paramagnetic ions have been made by a number of authors. The experimental data for ions is compared with that for metals, and in both cases the data appears to have an explanation in terms of the moment of the 3-*d* electrons. Ni-Cu and similar alloys should provide an interesting experimental test since Ni has zero nuclear moment, and an observable hyperfine coupling would be due to Cu.

**ZA8. Resonance in Terbium Doped Yttrium Iron Garnet (YIG) at Low Temperatures.** J. F. DILLON, JR., AND J. W. NIELSEN, *Bell Telephone Laboratories.*—Further studies of the variation of $H_{res}$ with crystal direction, i.e., $H_{res}$[hkl], in YIG(Tb) have been made.[1] At 1.5°K, 20-kMc measurements in the (110) plane show four sharp peaks in $H_{res}$. In the range of terbium concentration from 0.01 to 0.19 at.%, the height is linear with concentration. The height of all the peaks falls off with increasing temperature starting from the lowest temperatures. $H_{res}$ has also been measured in other crystal planes, showing the entire surface to be highly convoluted. $H_{res}$ in (110) at 1.5°K was measured over frequencies in the range 20 to 73 kMc. Of the four anomalous peaks, one does not change in height, and two increase a little faster than linearly with frequency. The peak about 18° from [100] grows in height at an increasing rate as the frequency is raised. At about 64 kMc, it abruptly becomes so broad that its height cannot be measured. This is presumed to indicate that $h\nu$ is approaching the separation of the two lowest energy levels of the rare earth ion. A slight variation of the angular position of the peaks with frequency is observed except for the peak along [110].

[1] J. F. Dillon, Jr., and J. W. Nielsen, Phys. Rev. Letters **3**, 30–31 (1959).

**ZA9. Spin-Lattice Relaxation of Low *k*-Number Spin Waves in Yttrium Iron Garnet. I. Frequency Dependence.** R. C. LECRAW AND E. G. SPENCER, *Bell Telephone Laboratories.*—Nonlinear effects using an rf magnetic field, $h$, parallel to the dc magnetic field have been studied in single-crystal spheres of highly purified yttrium iron garnet (YIG). Schlomann has proposed[1] that the $h_{crit}$ involved can be used to measure the relaxation time of low $k$-number spin waves. We have found that the relaxation time obtained in this way agrees with the spin-lattice relaxation time $T_{1\theta}$ of the uniform precession[2] (measured by the modulation technique), and is independent of surface roughness. In addition, this technique can be extended to lower frequencies than previously possible. We have measured the frequency dependence of $1/\gamma T_{1k}$ for low $k$ spin waves ($k \sim 10^3$ cm$^{-1}$) at room temperature from 6000 Mc/sec to 1300 Mc/sec. The most interesting feature is a rather deep minimum at 3000 Mc/sec, where $1/\gamma T_{1k} \cong 0.1$ oe. The physical processes giving rise to the minimum are being investigated. We have determined that rare earth impurities are not involved (at 300°K). The implications of this minimum on possible limiting line widths in YIG will be discussed.

[1] E. Schlomann, Detroit Magnetism Conference (1959).
[2] R. C. Fletcher, R. C. LeCraw, and E. G. Spencer, Phys. Rev. **117**, 955 (1960).

**ZA10. Spin-Lattice Relaxation of Low *k*-Number Spin Waves in Yttrium Iron Garnet. II. Temperature Dependence.** E. G. SPENCER AND R. C. LECRAW, *Bell Telephone Laboratories.*—Spin-lattice relaxation times of low $k$-number spin waves have been measured in high-purity single crystal yttrium iron garnet at low temperatures, using $h_{rf}$ parallel to $H_{dc}$ as described by Schlomann. At 4600 Mc/sec $1/\gamma T_{1k} = \Delta H_k = 170$ millioersteds (moe) at 300°K, and 25 moe at 4.2°K, with indications of extrapolating to considerably lower values at 1.5°K. The character of the line-width maximum at 39°K, due to paramagnetic rare earth impurity ions, is strikingly accentuated compared to our previous measurements on $\Delta H$ at 9340 Mc/sec.[1,2] The rare earth contribution in both cases is estimated to be approximately 150 moe. This is out of a $\Delta H_{max}$ of 370 moe[1] at 9340 Mc/sec, and out of only 175 moe at 4600 Mc/sec. The accentuation is due to the stronger frequency dependence of the residual compared to the rare earth relaxation. At ~39°K, the rare earth ions thus appear to contribute ~40% of the relaxation process at 9340 Mc/sec, and ~85% at 4600 Mc/sec. At the latter frequency the rare earth relaxation, even in these highly purified samples, is the dominant mechanism at temperatures below that of the line width maximum.

[1] E. G. Spencer, R. C. LeCraw, and W. Clogston, Phys. Rev. Letters **3**, 32 (1959).
[2] E. G. Spencer and R. C. LeCraw, Phys. Rev. Letters **3**, 130 (1960).

**ZA11. Harmonic Generation in Ferrimagnetic Crystals.** I. KAUFMAN, A. S. RISLEY, AND D. DOUTHETT, *Ramo-Wooldridge.*—The equation of motion of the magnetization in a ferrite predicts the generation of harmonics of the rf magnetization, when the ferrite is excited by an asymmetric rf field. Earlier experimenters demonstrated this phenomenon quite successfully, although the arrangements and results did not lend themselves to precise analysis of the role played by the material properties, applied fields, and geometry. By placing samples in a linearly polarized region of a microwave cavity,

resonant at 8.5 kMc/sec and 17 kMc/sec, we have measured simultaneously the amplitudes of fundamental power absorbed and second harmonic magnetization as a function of dc field, with 8.5 kMc/sec fields of constant intensity. The samples were disks (1-mm diam, 0.1-mm thickness) for which the demagnetizing fields enhance the asymmetry. Measurements have been made on single crystal and polycrystalline ferrites and YIG for various levels of rf drive. It was found that as high drive levels increase the line width, the second harmonic response broadens. The results are compared quantitatively with values expected from the equation of motion with Landau-Lifshitz damping included. At lower drive levels a comparison between results and predicted values at resonance has yielded close agreement.

**ZA12. Contribution of Tetrahedral $Ni^{2+}$ to the Anisotropy of Magnetic Spinels.** PHILIP K. BALTZER, *RCA Laboratories.*—Calculation of all the *3d* electronic states of $Ni^{2}$ on tetrahedral sites having cubic or tetragonal symmetry have shown how the $Ni^{2+}$ ion induces a spontaneous tetragonal distortion in its local environment. The anisotropy of the $Ni^{2+}$ ion on tetrahedral sites has been derived, by using the results of the above calculation, as a function of temperature, exchange field strength, and degree of local distortion. In most cubic spinels a few percent of the $Ni^{2+}$ ions present will be on the tetrahedral sites, although it is usually assumed that all the $Ni^{2+}$ is on the octahedral sites. The anisotropy contribution from tetrahedral $Ni^{2+}$ is calculated to be so large ($K_1 \approx +10^8$ ergs/cc at 0°K) that even such a small percentage of such ions would profoundly influence the properties of all magnetic spinels containing nickel. At the present time, the lack of single crystals has prevented anisotropy measurements of the tetragonal spinel $NiCr_2O_4$, in which essentially all the nickel is tetrahedral $Ni^{2+}$. One would predict from this theory, neglecting the influence of the $Cr^{3+}$ ions, that the direction of easy magnetization for $NiCr_2O_4$ is along the *c* axis of the tetragonal unit cell with an anisotropy energy of approximately $10^7$ ergs/cc required to rotate the magnetization into the direction of one of the *a* axes at 0°K.

**ZA13. Earth's Field Free Precession Apparatus.** ROBERT J. S. BROWN, *California Research Corporation.*—An earth's field nuclear induction apparatus at use at California Research the past several years uses samples from 0.5 cc to 6 liters. Thermal relaxation curves are obtained at fields from 0.5 to 7000 gauss. Signal-to-noise ratios are over 1000 for favorable samples. Solenoids produce polarizing fields up to 7000 gauss, power being supplied by storage batteries and switched by vacuum switches. Relays and timing circuits control polarizing current in two steps: A polarizing field can be applied for a chosen time, reduced and held constant for another chosen time, and reduced rapidly to zero. These times are controlled to within a few msec and measured to within 1.0 msec. Relays with coil windings in series with the polarizing current tell when currents flow and also actuate signal-receiving equipment. The low fields are used to obtain relaxation data at low fields after polarizing at strong fields. The signal-receiving coil can be either the polarizing coil or a separate one. Remanent magnetization can be measured by observing signal decay rates for a fluid sample in the presence of the magnetized sample. Helmholtz coils are provided to produce spin echos or to raise the frequency to 8 kc. Another earth's field apparatus is used in oil wells to observe proton precession signals from fluids in porous rocks surrounding wellbores.

## SUPPLEMENTARY PROGRAMME

**SP1. Capture-Gamma Determination of $V^{52}$ Levels.***† JOSEPH E. SCHWAGER,‡ *Lawrence Radiation Laboratory, Livermore* (introduced by Burton J. Moyer).—Thermal neutron capture-gamma radiation for $V^{52}$ have been observed with a fast-coincidence scintillation spectrometer recently developed for the Livermore one-megawatt pool-type reactor. A decay scheme has been established which verifies a previously proposed $V^{51}(d,p)V^{52}$ level scheme. Several low-energy crossover, without stopover, transitions have been observed: one for transitions from the 0.78-Mev level to the ground and 0.13-Mev levels (the latter being the more intense) but not to the 0.42 level, and two for transitions from the 0.83-Mev level to the ground state only. The 0.42-Mev level makes both crossover and stopover transitions to the ground and 0.13-Mev levels (the former being the stronger). Some evidence exists to suggest that the low-lying states arise from excitations of the $(1f_{7/2})^3$ proton configuration alone.

* Performed under the auspices of the U. S. Atomic Energy Commission.
† To be given at the end of Session I if the Chairman rules that time permits.
‡ Commander, U. S. Navy on special assignment at Lawrence Radiation Laboratory.

**SP2. New Method for Detecting a Possible Electron-Proton Charge Difference.*** J. W. TRISCHKA AND T. I. MORAN, *Syracuse University.*—Any difference from unity, *f*, of the ratio of proton-electron charge will manifest itself as a net electric charge on a body having an equal number of protons and electrons. We propose to deduce *f* from the motion in a horizontal, uniform electric field of a suspended macroscopic body so small that the presence on it of a single electronic charge is detectable. The particle might be suspended by carrying it aboard an earth satellite; or, in a terrestial experiment on a magnetizable body, by a magnetic field in a manner developed by Beams.[1] In the magnetic method the components of an ideal suspension field would be inhomogeneous in a vertical plane and would vanish along the horizontal line perpendicular to this plane. Then, if the body moves a distance *s* in a time *t* in a field *E*, $f = (2m_p/e)(s/Et^2)$, where $m_p$ is the proton mass and *e* the electronic charge. Reasonable values of the parameters in the expression for *f* yield $f = 2\times10^{-22}$. In this case, a spherical body would have a maximum radius $\leqslant 5\times10^{-3}$ cm in order to make detectable a charge on it $\leqslant 0.1e$.

* To be given at the end of Session MA if the Chairman rules that time permits.
[1] J. W. Beams, Phys. Today 12, 20 (1959).

**SP3. Computer Programs for Both APW Methods,*** M. M. SAFFREN, *General Electric Research Laboratory.*†—The APW method described by Saffren and Slater has been programed by the author for the WWI computer. The program with associated techniques by the author have been applied by Saffren to sodium, by Wood to iron, and by Allen to potassium. Later, the author discovered that the APW method described by Slater[1] could be formulated in a way that showed it to be superior to the method of Saffren and Slater. The author's program of this method along with associated techniques were applied by Saffren to sodium, by Wood to iron, and by Wood to crystal eigenfunctions in iron. The results of both APW programs for sodium are in excellent agreement with each other, and show good agreement with the cellular method

calculations of Howarth and of von der Lage and Bethe. The author thanks: D. J. Howarth for giving the author access to his APW programs, and access also to his programing notebooks, F. J. Corbato for permission to use his matrix diagonalization subroutine, and J. H. Wood for some help in testing some of the author's subroutines.

* This work was performed during the years 1955 through 1957 while the other was a member of the Solid State and Molecular Theory Group, MIT.
† To be given at the end of Session U if the Chairman rules that time permits.
[1] J. C. Slater, Phys. Rev. **51**, 846 (1937).

**SP4. Structure of Antineutrons and Neutrons.** GERTRUDE TIRING SCHWARZMANN.*—Antineutrons and neutrons are miniature atoms, positrons, and electrons describing minuscule circles about their central bodies in a classical microphysics, interpreting spin motion as full-fledged motion and corpuscle and wave state as alternate, equivalent states of the elementary entities of matter and those of light. All corpuscles are exceedingly thin circular rings of actual radius $r'$ spinning about one of their diameters as spin axis. Mu′ and 2 mu′ are the actual masses; sigma and 2 sigma the cross sections, $\frac{1}{2}$ mu′·$r'^2$ and mu′·$r'^2$ the moments of inertia, $h$ and $2h$ are the quanta of action, $h/2$ pi and $2h/2$ pi are the spin momenta, $h/4$ $pi^2$ and $2h/4$ $pi^2$ the moments of inertia of particles and photons, respectively. The satellites move in the two-branched locus of all points whose distances from two fixed points have a constant quotient, the central body in one of the foci, each branch an eccentric circle of radius $r$, and all concentric circles with radii smaller than the perihelion value of $r$ around one of the foci. Antineutrons and neutrons differ from H atoms mostly in magnitude; their beta decay mostly in name from the ionization of H atoms.[1]

* To be given at the end of Session U if the Chairman rules that time permits.
[1] G. T. Schwarzmann, Phys. Rev. **72**, 536, 744 (1947); **99**, 662, 677 (1955).

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Dessler, A. J.—M10
Devons, S.—C8
Dillon, J. F., Jr.—ZA8
Dintzis, Howard—T3
Doggett, W. O.—CA12
Donahue, D. J.—Q2
Douthett, D.—ZA11
Drell, S. D.—V5
Dresden, M.—V2, V3
Drisko, R. M.—PA11
Durand, L.—K7
Dyer, John N.—A2, A4
Edelstein, R. M.—EA10
Eden, R.—V6
Efremov, N.—U14
Eisner, Melvin—BA3
Enemark, D. C.—L4
Enge, H. A.—I9
Engelke, C. E.—C1
Enz, C.—V6
Erber, T.—V11
Erickson, William C.—M13
Erskine, J. R.—C11, MA11
Everett, A. E.—G10
Ewan, G. T.—JA9
Fabricand, B. P.—FA10
Fairbank, H. A.—XA8
Faissner, H.—Q11
Farkass, I.—W9, W10
Farmer, B. J.—MA9
Fazzini, T.—EA12
Feher, G.—N5
Feigley, B.—F12
Ferguson, G. A., Jr.—WA9
Fichtel, C. E.—L7
Fickler, Stuart I.—V1
Fidecaro, G.—EA12
Finegold, Leonard—N12
Finkelstein, D.—DA2, V4
Fischbeck, H. J.—JA6
Fivel, Daniel I.—PA5

Flippen, R. B.—ZA5
Follin, James W., Jr.—W12, W13
Fontana, Peter R.—CA7, FA8
Foreman, Bruce M., Jr.—Q1
Fowler, E. C.—UA1
Fowler, W. A.—H1
Fraed, Daniel S.—A1
Frank, William—PA4, PA7
Franzak, E.—U7
Franzini, P.—A5
Fraser, J. S.—Z1
Frautschi, S. C.—PA6
Freden, Stanley C.—A1, M8
Fredricks, R. W.—DA1
Freier, Phyllis, S.—L5
Friauf, R. J.—TA13, TA14
Fricke, G.—Q6, Q7
Friedberg, S. A.—ZA5
Friedland, S. S.—N13
Friedman, J. I.—EA4, Q4
Frisch, H. L.—S4, S5, S9
Fronsdal, C.—K5
Fujimoto, Y.—L8
Fujita, S.—U6
Funk, E. G.—JA5
Funsten, H. O.—WA7, WA8
Furth, Harold P.—A1, DA5
Futch, A. H.—DA4
Gajewski, R.—IA3
Galey, J. A.—MA11
Gallet, R. M.—E7
Galster, S.—F3
Garfinkel, A.—A5
Garwin, E. L.—B11
Gates, Duane C.—EA6
Geiger, J. S.—JA9
Gere, E. A.—N5
Gerhart, J. B.—F5, F13
Geschwind, S.—J3
Giffels, C.—TA2
Gilbert, Walter—V7
Ginsberg, D. M.—XA3
Ginther, R. G.—B7
Glaser, D. A.—VA4
Glauber, R. J.—G10, K3, PA10, ZA2
Glendenning, N. K.—XA12
Glover, R. E., III—XA1
Gold, Raymond—S11
Goldsack, S. J.—UA2
Goldschmidt-Clermont, Y.—EA12
Gonzalez-Vidal, J.—C7, C9
Goldberg, L.—A3
Goldberg, J. N.—V8
Goldberg, M.—C2
Goldberg, S.—FA10
Good, R. H., Jr.—N7
Gordy, Walter—BA4, FA2, J9, J10
Gourary, Barry S.—N6
Gove, H. E.—I2, YA8
Graham, R. L.—JA9
Grainger, R. J.—N13
Gram, P.—Q4
Gray, L.—B9
Graybeal, Jack D.—BA5
Green, A. E. S.—G6, G7
Green, Farno L.—F9
Greenwood, D. A.—ZA6
Greig, D.—N3
Greyber, Howard D.—S7
Griem, H. R.—E10, IA10
Grone, A. R.—TA4
Grossweiner, L. E.—TA12
Gruhn, C. R.—P7
Gudden, F. E.—Q6, Q7
Guevara, F. A.—IA4
Gutowsky, H. S.—BA2
Haase, E. L.—HA9
Hacskaylo, M.—TA10
Haeberli, W.—HA4
Haenni, H. P.—I3, I4
Hall, W. S.—I5
Halpern, I.—P7
Hamburger, E. W.—I1, Q3
Hammer, C. L.—B3
Hanak, J. J.—XA2
Hanna, G. C.—L12
Hannah, B. O.—C6
Harmatz, B.—JA5
Harth, E. M.—B9
Hartwig, G.—F2
Harvey, B. G.—C10
Hasegawa, S.—L8
Haskin, D. M.—L11
Hatcher, Robert D.—CA5
Havens, W. W., Jr.—WA6, Z7
Haymes, R. C.—L3
Hayward, Evans—G13
Heckman, Harry H.—A2, A4
Heckrotte, W.—DA4
Helfand, E.—S4, S9
Heller, C.—J2
Helm, R.—Q5
Henderson, J. W.—XA11
Heppner, J. P.—XB2
Hereford, F. L.—WA7, WA8
Herling, G.—YA4
Herman, Robert C.—W12
Herman, Roger M.—E1
Heer, C. V.—ZA7
Hess, W. N.—M7
Hibdon, Carl T.—Z9
Hill, H.—I11
Hill, H. A.—HA9
Hill, R.—C2
Hinks, E. P.—L12
Hinman, G. W.—TA2
Hirsch, H. R.—R8
Hirschel, Louis R.—FA9
Hobbie, Russell K.—UA4
Hoffman, R. A.—M4
Hopkins, J. C.—F5
Howe, D. A.—JA4
Huberman, M. N.—YA1
Huch, W. F.—M11, M12
Hughes, D. J.—WA2, WA11, Z10
Hughes, R. H.—W1
Hughes, V. W.—R1
Huizenga, J. R.—CA9, CA10
Hull, M. H.—PA2
Huntington, H. B.—TA4
Igo, G.—C7
Imhof, W. L.—HA2
Isihara, A.—E4
Jackson, H. E.—Z8
Jackson, Julius L.—DA7
Jacobs, J. A.—HA12, HA13
Jain, P. L.—L11
Jastram, P. S.—F11, JA2
Jastrow, Robert—RA1
Jauch, J. M.—V4
Jehle, Herbert—U1
Jenkins, Thomas L.—EA6
Jensen, Duane C.—M6
Jobes, F. C.—YA3
Johnson, J. R.—FA10
Johnson, R. G.—HA2
Jossem, E. Leonard—W2
Johnson, W. H., Jr.—G12
Kadanoff, Leo P.—K3
Kahn, P.—V2, V3
Kaiser, H. F.—U13
Kane, G.—EA13
Kane, J. V.—F4
Kane, W. R.—F10
Kaplan, R.—J1
Karplus, R.—M10
Katayama, Mikio—J10
Katzman, J.—L1
Kaufman, I.—ZA11
Kaufman, Sheldon—P10
Kaunisto, Leila—XA7
Kazes, E.—K10
Keller, E. L.—HA10
Kellman, S.—EA9
Kellogg, P. J.—M11, M12
Kendall, H. W.—EA4, Q4, Q5
Kennedy, E. F.—HA1
Kenney, Robert W.—EA6, EA11
Keren, J.—A5
Kerner, Edward H.—V12
Keyes, Robert W.—N4
Killeen, J.—DA4, M7
Kim, C. C.—HA12, HA13
Kim, Y. W.—J1
King, Harry F.—U2
King, J. M.—BA7
Kittel, Charles—D1
Klein, Abraham—PA5, S1
Kleitman, D. J.—PA10
Kneubuhl, F. K.—J5
Knox, William J.—YA2, YA9
Kohler, R.—R10
Korff, S. A.—L3
Koshiba, M.—L8
Koski, W. S.—J5
Koslov, S.—DA2
Kovacik, W. P.—EA9
Kraybill, H. L.—UA1
Krebs, James J.—BA1
Krumhansl, J. A.—ZA6
Kruse, T. H.—I6
Kuehner, J. A.—YA5, YA6, YA7
Kurbatov, J. D.—F12
Kurbatov, M. H.—F12
Kurita, Yukio—J9
Lam, D. G., Jr.—TA9
Landovitz, L. F.—K7
Lane, C. T.—XA10
Langer, L. M.—JA3, JA4
Lascoux, J.—V6
Laslett, L. Jackson—B3
Lassila K.—PA2
Laster, H.—L13
LeBlanc, J.—C2
Lebowitz, J. L.—S4, S5, S9
Lebowitz, J. M.—C1
Lecraw, R. C.—ZA9, ZA10
Lefrancois, J.—UA3
Leipuner, L. B.—A6
Leitner, J.—B9

Lemmer, R. H.—G7
Lenchek, A. M.—L13
Levi, M. W.—XA5
Levinson, C.—G1, G2
Levinthal, Cyrus—T1
Lewe, Chong Kook—W5
Lidofsky, L. J.—C8
Liebowitz, Benjamin—S12
Liefeld, Robert J.—W2
Liev, Elliott—S6
Lindgren, Ingvar—R5
Lipman, N. H.—EA12
Lipworth, E.—R3, R6
Little, William A.—XA6
Liu, D. C.—MA6
Liu, S. H.—N7
Loferski, Joseph J.—N11
Lohrmann, E.—L11
Lowen, R. W.—U5
Lounasmaa, O. V.—XA7
Maas, R. W.—M11
MacGregor, M. H.—PA1
Madigan, John R.—U10
Malamud, E.—MA3, MA4
Malenka, B. J.—PA9
Malik, S. S.—P3
Manning, John R.—U9
Maradudin, Alexei A.—N6
March, R. H.—MA2
Markowitz, S.—C7
Marr, R. B.—K7
Marrus, R.—R11
Marsh, B. B.—B10
Martin, H. J.—P8, P9
Mason, Conrad J.—A2, A4
Mather, R. L.—WA3
Matthews, D. L.—IA7
Maxson, D. R.—HA8
Mawardi, O. K.—IA3
Mayer, J. W.—N13
McConnell, H. M.—J2
McConville, G. T.—XA2
McCrary, J. H.—C5, HA5
McDaniel, R. E.—EA13
McDonald, F. M.—XB1
McGlinn, W. D.—V2, V3
McGowan, F. K.—P4, P5
McIlwain, C. E.—M9
McIntyre, J. A.—YA3
McKeown, Daniel—W8
McMillan, Robert C.—TA8
Mead, G. D.—EA8
Meadows, J. W.—WA4
Meechan, C. J.—TA5
Merrison, A. W.—EA12
Meshkov, S.—G3, HA11
Metzger, F. R.—HA14, P1
Michelini, A.—A5
Mihelich, J. W.—JA5
Miller, Douglas—UA4
Miller, S. L.—N12
Miller, W. C.—B6, C3, HA1
Mitchell, R. W.—BA3
Mito, I.—L8
Miyagawa, Ichiro—BA4
Montgomery, D. J.—TA6
Moore, M. S.—YA11
Moore, Neal—CA2
Moore, Richard L.—DA8
Morales-Amado, Arnulfo—WA10
Moran, T. I.—FA6, SP2
Moravcsik, M. J.—PA1
Morgan, I. L.—C5, HA5
Morrison, G. C.—YA1
Mossbauer, R. L.—MA8, QA2
Motz, H. T.—HA7
Mueller, H. J.—U11
Muether, H. R.—WA11
Mukherjee, A.—FA4
Müller, E. W.—X1
Munir, B. A.—UA2
Muss, D. R.—TA1
Myers, Orlo E.—FA11
Nainan, T. D.—F8
Naqvi, Ali M.—CA1
Narasimhaiah, H.—JA11
Nath, N.—P2
Nathan, Marshall I.—N12
Need, J. L.—P6
Nessin, M.—I6
Newton, R. R.—RA4
Ney, E. P.—M11, M12
Nickols, Norris A.—A2, A4
Neilsen, J. W.—J3, ZA8
Nielsen, O. B.—JA7
Nierenberg, William—R5, R11
Nijgh, G. J.—H3
Nishida, Y.—YA4
Nishimura, J.—L8
Nishina, Y.—N7
Noyes, H. P.—PA1
Nutley, H.—F13
O'Brien, E. E.—IA1
Oeser, J.—Q5
O'Friel, Z.—EA13
Ohmura, Haruko—CA6
Ohmura, Takashi—CA6
Olsen, W. C.—WA2
Öpik, E. J.—W11
Osborn, Richard K.—WA10
Osborne, M. F. M.—W4
Oster, Ludwig—E3
Pake, G. E.—J4
Palevsky, H.—WA2, WA11, Z10
Palmieri, J. N.—PA3
Parkinson, W. C.—H2
Patel, J. R.—N2
Patty, Richard R.—BA6
Paul, H.—EA12
Pearlstein, L. D.—Q10
Pendergast, R. J.—J6
Penfold, A. S.—B11
Percus, Jerome K.—S2, S3
Perez-Mendez, Victor—EA11
Perkins, Walton A.—EA11
Peterman, A.—K5
Petersen, F. R.—R7
Petree, M. C.—W6
Phillips, G. C.—Q13
Phillips, O. M.—IA2
Pinajian, J. J.—P6
Pinkston, W. T.—G5
Pixley, R. E.—F4
Plano, R.—A5
Ploughe, W. D.—HA15
Poirier, J. A.—VA3
Pool, M. L.—JA10, JA11
Pope, N. K.—MA5
Post, R. F.—DA3
Prager, Stephen—U8
Pratt, R. H.—CA8
Prenowitz, Edward—PA3
Preston, R. L.—P8, P9
Price, Robert E.—P11, Q3
Prodell, A.—A5
Prud'homme, J. T.—C5
Pyatt, K. D., Jr.—PA2
Quinton, Arthur R.—YA2
Quisenberry, K. S.—HA11
Radford, H. E.—R1
Rainwater, J.—EA10, Z7
Ramaswamy, M. K.—F11, G4, JA2
Randall, C. A.—L10
Randall, H. M.—T4
Rasmussen, V. K.—HA14
Rawcliffe, R. D.—G12
Reich, Allen D.—U10
Reich, C. W.—YA11
Reiss, H.—S9
Reppy, John D.—XA10
Richardson, J. M.—E7
Richert, S.—EA5
Risley, A. S.—ZA11
Roberts, A.—MA12
Roberts, R. B.—T2
Roberts, W. K.—MA6
Robinson, H. G.—R2
Rodberg, L. S.—G9, K9
Roesmer, J.—YA10
Rogers, E. H.—UA8
Rogers, K. C.—DA2
Rogers, R. N.—J7
Romanowski, T. A.—EA9
Rose, Marian H.—E8
Rosen, J. L.—Z6, Z7
Rosenberg, Leonard—PA8
Rosenthal, Jenny E.—E5
Roth, B.—Q9
Rothem, T.—P1
Rothman, M. A.—P2
Rothwell, P.—M9
Ruppel, H.—PA2
Russek, Arnold—W5
Rustad, B. M.—WA6
Rutherford, J. A.—E6
Sáenz, A. W.—WA9
Safford, G. J.—WA6
Saffren, M. M.—U15, SP3
Saladin, J. X.—HA4
Salkoff, Morris—BA9
Salzman, F.—EA2
Sampson, M. B.—P8, P9
Sandiford, D. J.—XA8
Sandin, R. B.—BA2
Sandweiss, J.—UA1
Sapp, R. C.—XA5
Sawicki, J.—XA12
Schectman, R. M.—EA1, EA7, MA1
Schein, Marcel—L8, L11
Schell, J. F.—V9
Schiff, L. I.—QA1
Schmidt, F. H.—F5
Schmidt, G.—DA2, DA9
Schoen, A. H.—U5
Schopper, H.—F2, F3
Schumacher, R. T.—ZA4
Schwager, Joseph E.—I8, SP1
Schwartz, Jack—R4
Schwartz, M.—A5
Schwartz, R. B.—F4, Z1

Schwarzmann, Gertrude Tiring—K11, SP4
Schwarzchild, A.—F4
Schwerdtfeger, C. F.—JA5
Scofield, Norman E.—S11
Segel, R. E.—F10
Segre, Emilio—VA2
Shea, M. F.—B6, C3
Shear, D. D.—IA11, IA12, IA13
Sheline, R. K.—Q8
Sherr, R.—HA6, I10, I11
Sherrill, M. D.—XA1
Sherwin, C. W.—G12
Shively, F. T.—A6
Shneiderov, Anatol J.—V10
Shugart, H. A.—R7
Silverman, A.—EA5
Silverman, Loretta E.—TA12
Simon, R. E.—N9, N10
Simons, J. C., Jr.—W9, W10
Singer, S. F.—DA6, L13, RA2, W11
Singh, P. P.—WA2
Skeel, W. L.—JA2
Slepian, Joseph—E9
Smith, D. R.—JA3, JA4
Smith, Felix T.—PA12
Smith, Frances M.—A2, A4
Smith, G. A.—UA1
Smith, W. G.—P5
Snow, William R.—E6
Snowdon, S. C.—B1
Speiser, D.—V4
Spencer, E. G.—ZA9, ZA10
Spicer, W. E.—N9, N10
Spriggs, Thurman E.—PA4
Spruch, Larry—PA8
Stager, C.—R10
Starner, J. W.—JA1, JA8
Stearns R. L.—WA11
Steinberger, J.—A5
Stelson, P. H.—P4, P5, C4
Stern, Edward A.—U4
Sternglass, Ernest. J.—EA14
Sternheimer, R. M.—MA10
Stewart, A. T.—MA2
Stewart, J. W.—X2
Stillinger, F. H., Jr.—S8
Stoering, J.—C2
Stolovy, A.—Z3
Stroth, J. E.—F5
Stubbins, Warren Fenton—UA7
Swanson, William P.—EA6
Sugihara, T. T.—YA10
Suh, Kiu S.—K1
Suhl, H.—U3
Swann, C. P.—HA14, P1
Taft, H.—UA1
Taketani, H.—I7
Tang, Y. C.—Q10
Tannhauser, D. S.—TA7
Tarbell, D.—B9
Tatcher, M.—C8
Tausner, Menasha J.—CA11
Taylor, C.—C2
Taylor, Raymond L.—IA5
Taylor, T. I.—WA6
Tefft, W. E.—TA9
Tendam, D. J.—HA15
Teng, Lee C.—B2
Teplitz, V. L.—G9
Terrell, James—QA3
Teucher, M. W.—L11
Thomas, G. E.—B7
Thorndike, E. H.—UA3
Tinlot, John H.—UA5
Todd, T. E.—CA12
Tomboulian, D. H.—W3
Tomnovec, F. M.—WA3
Toth, Kenneth S.—JA7
Townley, C. W.—F12
Townsend, J. R.—TA1
Treacy, E. B.—FA1
Trilling, George—A8
Trischka, J. W.—FA6, SP2
True, W. W.—G5
Tsai, Yung Su—K6
Tsipis, Costa—B8
Tuan, T. F.—PA11
Tzoar, Narkis—S1
Überall, H.—K8
v. Krzywoblocki, M. Z.—PA13
Valk, H. S.—PA9
Vandenbosch, R.—CA9, CA10
Van Patter, D. M.—P2, P3
Vaughn, F. J.—HA2
Vehse, W. E.—ZA4
Venkatesan, D.—L1
Verdier, R. F.—G10
Vervier, J.—F6
Vineyard, George H.—CA5
Vogt, Richard H.—Z4
Wachtman, J. B., Jr.—TA9
Wade, W. H.—C9
Wageman, W. E.—IA4
Walecka, J. D.—PA6
Walker, E. H.—DA6
Walker, R. L.—EA3
Walker, W. P.—TA3
Walt, M.—HA2
Walter, R. L.—B6, C3
Walters, Virginia F.—S10
Walton, R. B.—C12, WA5
Wang, T. P.—L2
Ward, G. D.—E7
Warner, Robert E.—UA5
Warsh, K. L.—MA11
Watts, T. L.—YA3
Weatherly, T. L.—BA8
Webb, W. H.—P6
Weddell, James B.—Q12
Wegener, Horst—F1
Wegener, H. E.—I5
Weill, R.—MA3, MA4
Welch, J. A., Jr.—M6
Welsh, Robert E.—Q2
Weneser, J.—CA3
Whalen, J. F.—WA4
Whitaker, W. A.—M6
White, D. H.—EA1, EA7, MA1
White, M. B.—R3, R6
White, R. Stephen—A1, XB3, M8
Wieder, B.—E7
Wiedmann, W.—MA8
Wiese, Wolfgang—IA10
Wiggins, J. S.—N13
Wikner, J. L.—WA5
Wildermuth, K.—Q8, Q9, Q10, Q11
Wilets, L.—G8
Wilkinson, R. G.—JA6
Williams, C. E.—W7
Williams, Dudley—BA6
Williams, Quitman—BA8
Williamson, M.—C2
Williamson, T. G.—WA7, WA8
Wills, J.—G6
Wilson, D. K.—N5
Wilson, R. G.—JA10
Wilson, Richard—UA3
Wilson, R. R.—UA6
Wimmel, Hermann K.—E2
Winckler, J. R.—M1, M3, M4
Winocur, J.—R11
Wojtaszek, J. H., Jr.—I9
Wolf, S. E.—A5
Wood, J. L.—WA5
Wyatt, P. J.—G6
Wysocki, Joseph J.—N11
Yagoda, Herman—M5
Yang, C. P.—ZA1
Yearian, M.—Q5
Yevick, George J.—S2, S3
Yokoi, K.—L8
Young, J. C.—C12, YA10
Young, O. B.—L2
Zachariasen, F.—V5
Zeleny, W. B.—K4
Zilsel, P. R.—S10
Zorn, J. C.—FA7, FA8
Zwanzig, R.—QA4
Zwerdling, S.—X4

## Second Announcement of the 1960 June Meeting in Montreal

The 1960 June meeting will be held in Montreal, on the campus of McGill University, on Wednesday, Thursday, and Friday, June 15–17, 1960. Of equal importance with the meeting dates and the deadline date is **June 4,** which is the latest date at which reservations will be accepted by our official hotel, the Sheraton-Mt. Royal Hotel, Montreal, Canada. After its quota for us is booked, it will place later applicants in the Hotel Laurentien, but all reservations should be made by writing to the Sheraton-Mt. Royal. Write as soon as possible, and do not wait for the June Bulletin, which may or may not be in your hands by June 4! Those who are willing to share twin-bed rooms will stand a better chance of getting accommodations.

At this meeting our Division of Electron Physics will have its major sessions of the year, and in addition we expect the participation of the Divisions Fluid Dynamics and Plasma Physics.

Deadline day for abstracts is Friday, April 8. Not later than that day, abstracts must be received at the office of the Society: address them to American Physical Society, Columbia University, New York 27, New York.

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## Preliminary Announcement of the 1960 Thanksgiving Meeting at Chicago

The 1960 Thanksgiving meeting will be held at Chicago, on the campus of the University of Chicago, on Friday and Saturday, November 25 and 26. The official hotel will be the Windermere, at 1642 East 56th street. Deadline will be announced in the June Bulletin.

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### *Ladies' Programme for the Washington Meeting*

*(Item added to proof, and not proofread)*

The Ladies' Programme has been arranged by a Committee of which Mrs. Arthur E. Ruark is Chairman.

On Monday, April 25, from 9:30 to 11 A.M., coffee will be served in the Madison Room of the Sheraton-Park Hotel.

On Tuesday, April 26, at 9:00 A.M., there will be a tour by chartered bus from the Sheraton-Park to the azalea gardens and fern valley of the National Arboretum, continuing to the museum and gardens of Dumbarton Oaks, with luncheon at Olney Inn. The price of tour including luncheon will be five dollars. Return to the hotel will be at 2 P.M. roughly. At 4:30 P.M. begins the tea at the National Bureau of Standards (page 221 of this Bulletin) to which members of the Society and their families are cordially invited.

For Wednesday, April 27, a tour of the National Gallery or a tour of the White House may be arranged. On Wednesday evening is held the banquet of the Society (page 221 of this Bulletin) at which the ladies will be more than welcome.

Advance registration may and should be made by writing to Mrs. Arthur E. Ruark, 4101 Byeford Court, Kensington, Maryland. At the meeting itself the ladies may register, or others may register for them, at the registration-desk of the Society, BUT ONLY UP TO ONE O'CLOCK ON MONDAY AFTERNOON.

## 1960 Topical Conference on Neutron Diffraction in Relation to Magnetism and Chemical Bonding

A Conference on Neutron Diffraction in relation to Magnetism and Chemical Bonding, sponsored by Oak Ridge National Laboratory, the Office of Naval Research, and The American Physical Society, will be held in Gatlinburg, Tennessee, April 20–22, 1960. Members desiring more detailed information should write to E. O. Wollan, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Abstracts of contributed papers may be sent to E. O. Wollan (*not to the Secretary of the Society!*) and must reach him not later than March 1, 1960. *Abstracts must conform to the same regulations as are imposed on those submitted for general meetings of the Society; otherwise they will not be printed.* Take note that it is the prerogative of the management of the Conference to accept or decline contributed papers that are offered.

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## Second Topical Conference on Reactions between Complex Nuclei

A second conference on Reactions between Complex Nuclei will be held at May 2, 3 and 4, 1960, at Gatlinburg, Tennessee. Any member of the Society who desires more detailed information should write to Dr. R. S. Livingston, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Abstracts of contributed papers may be sent to Dr. Livingston (*not to the Secretary of the Society!*) and must reach him not later than April 2, 1960. *Abstracts must conform to the rules and instructions imposed on abstracts for the general meetings, else they will not be published in the Bulletin.* Take note that the management of the Conference has plenary authority to accept or decline contributed papers that are offered.

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## 1960 Gaseous Electronics Conference

The Thirteenth Annual Gaseous Electronics Conference will be held at Monterey, California, on October 12–14, 1960, under the sponsorship of the U. S. Naval Postgraduate School and that of the Division of Electron Physics of the American Physical Society. The scope of this conference embraces fundamental knowledge in the whole field of ionization and discharge in gases, not excluding plasma dynamics; but papers on specific devices will not be admitted.

Abstracts of contributed papers may be sent to N. L. Oleson, Conference Secretary, U. S. Naval Postgraduate School, Monterey, California, and must reach him not later than August 24, 1960. *Abstracts must conform to the same regulations as are imposed on those that are submitted for general meetings of the Society; otherwise they will not subsequently appear in this Bulletin.* As always, it is the prerogative of the management of the Conference to accept or decline contributed papers as it chooses. The Conference Committee will not accept a greater number of contributed papers than is compatible with its intent to keep the meeting within three days, to avoid simultaneous sessions, and to provide adequate time for presentation and discussion of the papers that are accepted.

# Proceedings of the American Physical Society

## Minutes of the Divisional Meeting of the Division of Plasma Physics

### Held in Monterey, California, December 3–5, 1959

THE first Divisional Meeting of the Division of Plasma Physics was held at the Naval Postgraduate School, Monterey, California, on December 3–5. The arrangements for the meeting were made by a committee consisting of Frederic Coensgen (Chairman), Charles Damm, and Norris Carlson, and by Norman L. Oleson of the Naval Postgraduate School. The combination of perfect weather and the beautiful campus of the Naval Postgraduate School made outdoor discussions a real pleasure, and King Hall is one of the finest auditoriums in the country. There were 423 registered participants at the meeting, considerably more than expected. Even more unexpected was the large number of contributed papers (130)—more than twice the number anticipated. This had the unpleasant consequences of severely limiting the number of invited papers and of requiring parallel sessions throughout the meeting (except during the one session of invited papers).

The banquet was held at the Officers Club of the Postgraduate School. The Chairman of the Division presided and over 350 people were present to hear the interesting (and entertaining) after-dinner speech by Edward Teller on "A Long View of Sherwood."

Melvin B. Gottlieb, *Chairman*
Division of Plasma Physics

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### Thursday Morning at 9:45

Spanagel Hall

(J. A. Phillips presiding)

**A1. Instability of Plasmoids with No External Currents.*** L. N. Zadoff, Julian Reinheimer, M. Bernstein, *Republic Aviation Corporation, Missile Systems Division.*—The possibility of confinement of a plasma by a magnetic field to a finite volume of space in a three-dimensional geometry, with currents limited to the interior or the surface of the plasma, has been investigated by an application of the Chandrasekhar-Fermi virial theorem.[1] The assumptions are made that the plasma behavior is governed by the Navier-Stokes equation, including the magnetic term and a scalar pressure. The gravitational potential and viscosity term is neglected. The virial theorem is applied to a large sphere surrounding the smaller volume which contains the plasma. For finite magnetic field energy, the surface integrals appearing in the virial theorem vanish as the radius of the sphere is increased without bound. The result is that the second time derivative of the second spatial moment of the mass must be positive definite.

* This work supported by the Air Force Special Weapons Center.
[1] S. Chandrasekhar and E. Fermi, Astrophys. J. 118 (July, 1953).

**A2. Electron Sheath Instability.*** C. W. Hartman and D. H. Sloan, *University of California, Berkeley.*—In a crossed field mirror device, the electron sheath is made stable for observation by replacing the neutral plasma bulk by a rigid secondary emission surface. Conditions analogous to the charge separation field at the surface of a magnetically confined plasma can now be set up with dc electric fields. The sheath is stable over large areas for cyclotron $\omega_c \geq \omega_p$ of electron plasma, as long as $\omega_c$ remains less than $\omega_T$. However, if $\omega_c$ exceeds cutoff $\omega_T$ of possible transverse magnetic electromagnetic waves travelling parallel to the sheath, stability is lost after a few microseconds. Greatly increased $B$ only hastens the onset of the instability, and is completely ineffective in restraining these local outgrowths. Radio energy generated is entirely consumed by other electrons, and does not emerge. Megawatts/cm$^2$ are involved. As the sheath advances, the plasma may follow. Most plasma heaters have $\omega_T < \omega_c$. It is hoped that this instability is not completely within the sheath but also depends upon the presence of the secondary emitter.

* This project was partially supported by the Air Force Cambridge Research Center, U. S. Air Force, and the Wright Air Development Center, U. S. Air Force.

**A3. Electrostatic Instabilities in Slightly Inhomogeneous Plasmas.** N. A. Krall and M. N. Rosenbluth, *General Atomic.*—The stability of plasmas against plasma oscillations has been previously explored for the case of an infinite uniform plasma, and other cases have been studied in the limit of long wavelength and low frequency. The present work is an attempt to treat a nonuniform system by a perturbation procedure, without the previous restrictions on wavelength or frequency. The case considered is $f_0 = \exp(-\alpha v^2)[1+\epsilon f_{01}+\epsilon^2 \cdots]$, $\mathbf{B} = B_0(1+\epsilon \cos Kx)\mathbf{i}_z$. The frequency of a plasma oscillation propogating in this system is expanded in powers of $\epsilon$, $\omega = \omega_0 + \epsilon\omega_1 + \epsilon^2\omega_2 + \cdots$, where $\omega_0$ is the frequency of propogation for the uniform plasma case $\epsilon = 0$. Only longitudinal electrostatic waves are considered—this is a good approximation if $(k^2c^2/\omega_p^2) \gg 1$, where $\omega_p$ is the plasma frequency. The presence of the nonuniformity introduces Fourier components other than the usual $e^{i(\mathbf{k}\cdot\mathbf{x}-\omega t)}$. In particular, $f_1 = e^{i\omega t}[f_{10}e^{i\mathbf{k}\cdot\mathbf{x}} + \epsilon f_{11}e^{i(\mathbf{k}+\mathbf{K})\cdot\mathbf{x}} + \epsilon f_{1-1}e^{i(\mathbf{k}-\mathbf{K})\cdot\mathbf{x}} + \cdots]$. The use of an expansion procedure means that we would miss any features involving nonexpandable functions of $\epsilon$. Such features might include particle trapping by the oscillation. Under these restrictions, for normal mode analyses where $\omega_0$ is always real, we write $\omega = \omega_0 + \epsilon\omega_1 + \epsilon^2\omega_2$, and conclude that $\omega_1$ vanishes and $\omega_2$ is real, hence the plasma remains stable.

**A4. High-Frequency Trapping Instabilities in a Nonuniform Plasma.** M. N. Rosenbluth and N. A. Krall, *General Atomic.*—A nonuniform equilibrium plasma is studied for

instabilities arising from trapping of particles by plasma oscillations. Nonuniform plasmas contain inhomogeneous magnetic fields B, giving rise to an average drift velocity $v_d=(1/B)(dB/dx)\Omega v_{th}^2$; $\Omega$ is the cyclotron frequency, $v_{th}$ is the thermal velocity. Trapping could occur when a plasma wave moves with phase velocity $\omega/k$ nearly equal to $v_d$. We consider longitudinal electrostatic oscillations, with wave number $\mathbf{k}$ perpendicular to $\mathbf{B}$; $\mathbf{B}=B_0(1+\epsilon x)\mathbf{i}_z$, causing a drift in the $y$ direction. The corresponding uniform plasma has eigenvalues near multiples of the electron and ion cyclotron frequencies. We consider only the important mode at the ion cyclotron frequency $\Omega_i$, and find solutions corresponding to growing waves. The growth rates depend on $v_d$ and $v_{th}$, but were several orders of magnitude smaller than $\Omega_i$. These growths occur only for $v_{phase}=\Omega_i/k\cong v_{drift}$ as expected, corresponding to quite large $k$; thus only wavelengths smaller than the ion Larmor radius by a factor $(v_{drift}/v_{th})_{ion}$ are unstable. We conclude that the effect of the nonuniformity is a fast (compared with diffusion times), highly localized (compared with ion Larmor radii) disturbance, which may well dissipate itself without damage to the body of the plasma, but which could certainly have an effect on diffusion, resistivity, and other plasma properties.

**A5. Stability of Uniform Plasmas with Respect to Longitudinal Oscillations.** PETER D. NOERDLINGER,* *California Institute of Technology.*—It is possible to relate the dispersion formula for longitudinal oscillations in an infinite, uniform, collision-free plasma with no magnetic field to the complex potential of a line charge distribution on the real axis of the phase velocity [$u=\omega/k$] plane. If the initial velocity distribution averaged over directions orthogonal to the direction of propagation is $f(v)$, the plasma is stable if and only if

$$U(u)=P\int_{-\infty}^{\infty}\frac{f'(v)dv}{v-u}$$

is negative at the minima of $f(v)$ on the real axis, with unimportant exceptions. In particular it is shown that single-peaked distributions are stable, while those with very sharp [e.g., nondifferentiable] minima or with a zero of $f$ between two peaks are not. The charge analogy yields information on the wavelengths for which oscillations can grow and on rates of growth. Examples are given, including the case of two identical interpenetrating hot plasmas. A limited generalization to transverse oscillations is given.

* Howard Hughes Fellow; work done in part on National Science Foundation Summer Fellowship.

**A6. Stability of a Plasma Torus. I. Mathematical Formulation.*** B. R. SUYDAM, *Los Alamos Scientific Laboratory,* AND R. LÜST, R. D. RICHTMYER, AND A. ROTENBERG, *Institute of Mathematical Sciences, New York University.*—An energy principle[1] has been employed to study the stability of a torus of plasma. In the model studied, the plasma is treated as a perfectly conducting perfect gas. In the equilibrium configuration, the only currents which flow are confined to an infinitesimally thin surface layer. Thus the model is the toroidal analog of a cylindrical pinch studied by Rosenbluth,[2] so that a comparison of our results with his should give us some insight into the effects of the additional curvature and of closing the system.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] I. B. Bernstein, E. A. Frieman, M. D. Kruskal, and R. M. Kulsrud, Proc. Roy. Soc. (London) **A244**, 17 (1957).
[2] M. N. Rosenbluth, Los Alamos Report No. LA-2030 (1957) and Third International Conference on Ionization Phenomena in Gases, Venice (1957).

**A7. Stability of a Plasma Torus. II. Calculations and Results.*** A. ROTENBERG, R. LUST, R. D. RICHTMYER, AND D. LEVY, *Institute of Mathematical Sciences, New York University,* AND B. R. SUYDAM, *Los Alamos Scientific Laboratory.*—The equations given in the previous paper describing the energy change $\delta W$ associated with an arbitrary displacement have been examined. In the limit of large aspect ratio (ratio of the large radius to the small radius) of the torus it was observed that for perturbations with wavelengths comparable to the circumference the curvature still has some influence and in this case the modes around the small radius are strongly coupled. The important toroidal perturbations will be described briefly and some indications of areas of stability as compared with the cylinder will be given based on the results of a code written for the IBM 704.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**A8. Stability of a Diffuse Linear Pinch with an Almost Isotropic Pressure Tensor.*** KENNETH SCHWARTZ, *University of California, Los Angeles.*—An energy integral,

$$W=1/2\pi\int_0^b[f(d\xi/dr)^2+g\xi^2]dr,$$

for a diffuse linear pinch with an anisotropic pressure tensor is obtained from a general energy integral which is similar to the one derived by Bernstein et al.[1] If one considers the parameters which distinguish the pinch with anisotropic pressure tensor from the one with isotropic pressure tensor as being sufficiently small, then one can expand the integrand about isotropy. The zero order terms give the energy principle for a pinch with isotropic pressure tensor, the minimization of which has already been treated by Newcomb.[2] The addition of the first order terms modify the problem considerably; in particular a new additive term, $r\delta$, arises in $f$ which can be positive, or negative, or zero. For $r\delta$ positive or zero the minimization can be handled by the theory developed by Newcomb. However, the pinch will always be unstable if $r\delta$ is negative.

* Supported by the U. S. Atomic Energy Commission through the Lawrence Radiation Laboratory, Berkeley and Livermore.
[1] Bernstein et al., Proc. Roy. Soc. (London) **A244**, 17–40 (1958).
[2] William Newcomb, UCRL 5447.

**A9. Plasma Stability with ac Confining Fields.*** N. ROSTOKER, *General Atomic.*†—If the confining field external to a plasma is a rotating magnetic field of constant magnitude instead of a time-independent field, the stationary state of the plasma is unaltered. When the plasma is treated as an incompressible fluid, the normal modes of oscillation of the system are determined by a Mathieu equation. Stable and over-stable solutions exist for a set of bands which are well known in the study of crystals, for example. As the wavelength of the perturbation is varied, solutions of both types are obtained. This type of confinement cannot be stable in disagreement with the result of Weibel. However, the growth rate is reduced as a result of the ac confining fields which may be of practical significance. To obtain quantitative results it is necessary to consider the finite compressibility of the plasma. The mathematical problem is then considerably more complicated, but the solutions have the same qualitative properties.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Research Foundation.
† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

**A10. Stability of Electromagnetic Plasma Confinement in Spherical Geometry.*** J. W. BUTLER, *Argonne National Laboratory.*—In principle, a hot plasma body may be contained by the pressure of a radiofrequency electromagnetic field. A partial stability analysis has been effected for a model consisting of a conducting fluid sphere held in pressure equilibrium at the center of a spherical resonant cavity by exciting a rotating $TE_{111}$ mode and a steady magnetic field parallel to the rotation axis at infinite distance. The stability of the system against adiabatically slow deformations is treated by computing, to second order in $\delta$, the work done in deforming the core boundary into the shape $r=r_0+\delta X$, where $r_0$ is the un-

disturbed core radius and $X$ is a sum of spherical surface harmonics $X_l^s$ with arbitrary coefficients. Criteria for instability may be obtained by taking $X=X_l^s$, thus computing only the diagonal coefficients of the quadratic energy form. For core diameters less than about $\frac{3}{10}$ of the cavity diameter, the equilibrium is found to be unstable by taking $l=1$ or 2; for larger cores, the number of unstable $l$, $s$ values increases rapidly. First order coupling between the degenerate modes occurs for $l=2$ and $s=1$ or 2.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**A11. Pinch with Rotating Plasma.*** E. GERJUOY AND M. N. ROSENBLUTH, *General Atomic.*—The magnetohydrodynamic stability of an infinitely conducting incompressible plasma, in the shape of an infinitely long circular cylinder within an external conductor, compressed by external $B_\theta$ and $B_z$ against internal $B_z$, has been investigated in the circumstance that the plasma has an angular velocity about the $z$ axis of the cylinder. For constant angular velocity the differential equation for the perturbed total (magnetic plus hydrodynamic) pressure inside the plasma is solved by Bessel functions, and one concludes that the rotation, in this case necessarily produced by a radial electric field proportional to radius, makes the plasma less stable than in the absence of such internal electric fields.[1] For small nonconstant angular velocity, or for small deviations from constant angular velocity, results can be obtained by perturbation theory, and these will be discussed.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Energy Research Foundation.

† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

[1] M. Rosenbluth, Los Alamos Report LA-2030 (1956), declassified; R. J. Tayler, Proc. Roy. Soc. (London) **B70**, 1049 (1957); V. D. Shafranov, J. Nuclear Energy **2**, 86 (1957).

## THURSDAY MORNING AT 9:45

## King Hall

## (C. M. VAN ATTA presiding)

**B1. Influence of End Losses and Field Trapping in Magnetic Compression of Plasmas.** ALAN C. KOLB, *U. S. Naval Research Laboratory.**—According to Grad's theory[1] of losses in a collision-dominated plasma, the rate at which particles are lost out the ends through a mirror (or "point cusp") is proportional to the length of the coil $L$ and the mirror ratio $R$ and inversely proportional to the mean ion velocity. A further analysis which takes into account the compressional heating and pressure balance shows that the effect of these losses is to decrease the plasma radius and density and to increase the particle velocities relative to the case where end losses are negligible. The theoretical and observed confinement times are in accord and the duration of the neutron emission is correlated with the confinement time for a range $LR=7$ to 75 for field strengths of $\sim$70 000 gauss generated by $2.5\times10^6$ amp currents with a half-period of $\sim$14 $\mu$sec. The effect of reverse trapped magnetic fields on the over-all characteristics of the discharge and on neutron production will be discussed.

* Jointly supported by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] H. Grad, New York University Report, NYO-7969 (1957) (unpublished).

**B2. Soft x Radiation from a Magnetically Compressed Plasma.** T. F. STRATTON, F. C. JAHODA, AND G. A. SAWYER, *Los Alamos Scientific Laboratory.*—Previous work on soft x radiation from high temperature deuterium plasma experiments, has shown that the radiation is emitted from the ionized gas. Continuing time-resolved study of the spectral characteristics of Scylla has resulted in the identification of a sharp low wavelength cutoff in the neighborhood of 8 A at the peak magnetic field. Comparison of the experimental ratios of the intensities transmitted through absorbers having $K$- or $L$-absorption edges in the range of 8 to 15 A, with ratios calculated assuming that the high frequency cutoff is the result of a Maxwellian electron velocity distribution, results in an electron temperature assignment of $230\pm40$ ev. Absolute intensity determinations with a calibrated scintillator-photomultiplier and an ionization chamber show that $dE/d\lambda$ near the short wavelength cutoff is larger by a factor of several hundred than that expected for free-free bremsstrahlung from a pure deuterium plasma at the temperature and density postulated. Introduction of known fractions of $N_2$, Ne, and Ar, into the discharge changes the spectrum and intensity in a fashion indicating that the large $dE/d\lambda$ observed is the result of free-bound (recombination) radiation from about 1% of contamination material with $Z\geq7$.

**B3. Photoelectric Spectroscopy of a Magnetically Compressed Plasma.*** F. C. JAHODA, G. A. SAWYER, AND T. F. STRATTON, *University of California, Los Alamos Scientific Laboratory.*—In conjunction with the soft x-ray observations on Scylla wavelength resolved photoelectric measurements were made in the visible spectral region at the time of peak magnetic field during the second half-cycle. The discharge was viewed axially with the coil center imaged on the slit of an ARL Quantograph fitted with six photomultiplier detectors. The observed composite spectrum is consistent with the predicted bremsstrahlung spectrum from a thermal electron distribution with deuterium line and recombination radiation from a cooler envelope region superposed. The absolute value of the brightness, which is relatively insensitive to the temperature, determines an electron density of $7\pm1\times10^{16}$ cm$^{-3}$ if an electron temperature of 230 ev and an optical depth of 2 cm are assumed. Impurity radiation contributes much less than in the x-ray region, but limits the density determination to being an upper bound. During the first half-cycle of the magnetic field, before the shock heating, the spectral profile and intensity of the $D_\beta$ line indicates a significantly lower temperature and compression.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**B4. Observations on a High Current PIG Discharge with Mirror Geometry.** M. WEINRICH AND L. M. GOLDMAN, *General Electric Research Laboratory,*—In an attempt to produce a high degree of ionization in a mirror device, a split anode PIG discharge tube has been constructed. The tube is 6 in. in diam and approximately 30 in. long. The mirror ratio is 2:1 and magnetic fields from 2–18 kg at the center of tube are used. Measurements of the circuit paramenters show a negative characteristic for the discharge. The current is limited by an external resistor to values ranging from 20 to 3000 amp. The anode voltage is found to be almost independent of the current but depends on the magnetic field. One can fit the observations with either $V_a=AH+C$ or $V=D(H)^{4/5}$ where $A$, $C$, $D$ are constants. Microwave measurements show a high

percentage peak ionization. With the current crowbarred, transmission experiments with 36 kMc and 10 kMc microwave power show a decrease of electron concentration from $1.4\times10^{13}$ to $1.1\times10^{13}$ electrons per cc in 50 to 200 $\mu$sec depending on voltage, magnetic field, and current at crowbar time.

**B5. Rapid Magnetic Compression Experiment with PIG Preionization.** L. M. GOLDMAN, H. C. POLLOCK, J. ROUVINA, W. F. WESTENDORP, *General Electric Research Laboratory.*—A rapid magnetic compression device in which the gas is preionized by a PIG discharge has been constructed. The device consists of a ceramic vacuum tube 4 in. in diam surrounded by a single turn brass coil $4\frac{3}{4}$ in. i.d. and 7 in. long with auxiliary coils and electrodes to produce the PIG discharge. The tube diameter is approximately twice that used in similar experiments at LASL[1] and NRL.[2] A mirror ratio of 1.1:1 on the axis is produced by shaping the turn.[1] The effects of the strength and orientation of the quasisteady magnetic fields on the rapidly compressed plasma will be discussed with stress on the time dependence of the neutron yield and the velocity of the initial shock.

[1] W. C. Elmore, E. M. Little, and W. E. Quinn, Phys. Rev. Letters **1**, 32 (1958).
[2] H. R. Greim, A. C. Kolb, and W. R. Faust, Phys. Rev. Letters **2**, 281 (1959).

**B6. Plasma Compression by Rising Axial Magnetic Fields (Orthogonal Pinch).*** J. W. MATHER AND A. H. WILLIAMS, *University of California, Los Alamos Scientific Laboratory.*—The radial distributions of the magnetic field have been measured in argon and deuterium (for field rising at the rate of $10^{10}$ gauss/sec). For argon, and to a less extent in deuterium, some of the external field leaks through the gas current layer during its initial formation to be subsequently trapped and compressed. The result is a plasma confined as a cylindrical annulus between axial fields. Oscillations of the magnetic field are interpreted as radial hydromagnetic oscillations of frequency $\omega=B_z/(\rho_l)^{\frac{1}{2}}$ where $B_z$ and $\rho_l$ are the equilibrium field and line mass density, respectively. For deuterium, at maximum compression, the external field rapidly penetrates the current layer. This diffusion leads to large induced electric fields ($E_\theta$) in the plasma which suggests a rapid plasma heating mechanism by acceleration of ions and electrons. For moderate central fields ($\sim$20 kg) and high density plasmas ($\sim10^{17}$/cc) sufficient heating and thermalization can occur to achieve temperatures of $\sim$500 ev. Reversed magnetic fields of short duration are occasionally observed during the second (i.e., first compression) cycle; during the second compression, 1/2 cycle later, reversed fields of longer duration (1-1.5 $\mu$sec) are recorded.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**B7. Numerical Magnetohydrodynamic Calculation of Plasma in Axial Field.*** J. W. SHEARER AND J. R. WILSON, *Lawrence Radiation Laboratory, Livermore.*—The one-dimensional magnetohydrodynamic equations of deuterium plasma moving under the influence of an axial ($B$-$Z$) field, are numerically integrated in cylindrical Lagrangian coordinates, using boundary conditions which correspond to the Los Alamos "Totem Pole" machine,[1] and to some of the NRL experiments.[2] In the hydrodynamic equations, an additional term $B^2/2\mu$ is added to the pressure, and the energy equation is modified by the addition of ohmic heating, radiation loss (by both bremsstrahling and characteristic radiation), and thermal conduction terms. The magnetic field equations strictly obey Faraday's Law, but the diffusion is approximated. A gamma law equation of state is used, with approximate corrections for the low temperature, partially ionized region. It is found that no special technique is required for shock smoothing,[3] since ohmic heating and thermal conduction provide a natural mechanism for spreading out the shock boundary.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] E. M. Little and D. B. Thomson, "Magnetic compression of shock preheated plasma," LA-2202.
[2] A. C. Kolb and H. R. Greim, "Dense plasmas confined by external fields," *Proceedings Fourth International Conference on Ionization in Gases, Uppsala, 1959* (North-Holland Publishing Company, Amsterdam, 1959).
[3] J. Von Neumann and R. D. Richtmyer, J. Appl. Phys. **21**, 232 (1950).

**B8. Electron Energy Distribution and Temperature of the Plasma in a Mirror Machine.*** R. E. ELLIS, W. A. PERKINS, AND R. F. POST, *Lawrence Radiation Laboratory, Livermore.*—By means of a scintillator-absorber technique, the distribution in energy of the flux of electrons, escaping through one mirror from the plasma in the Table Top[1] pulsed magnetic mirror machine, is determined as a function of time and machine parameters, and the results analyzed by computer techniques. A typical plasma electron temperature of 13 kev is deduced for the case of a peak pulsed field of 16 kilogauss, a rise time to peak value of 600 $\mu$sec and a $1/e$ field decay time of 14 msec, for data taken at one msec subsequent to firing of the source and initiation of the magnetic field. For a peak field of 32 kilogauss, a temperature of about 27 kev is inferred. Variations in plasma electron temperature for different dc injection fields are also discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] F. H. Coensgen, F. C. Ford, Proc. Second Conf. Peaceful Uses Atomic Energy (Geneva, 1958), **32**, 266.

**B9. Radial Distribution of Plasma in a Mirror Machine.*** W. A. PERKINS, R. E. ELLIS, AND R. F. POST, *Lawrence Radiation Laboratory, Livermore.*—The radial distribution of the electrons escaping axially from the plasma in the Table Top mirror machine has been measured with scintillation techniques. Assuming that the energy distribution of electrons is independent of radial distance from the axis and that no significant corrections for ambipolar effects are needed, one can deduce the radial distribution of the particles in the plasma by using the known magnetic field configuration. The measurements indicate a gaussian distribution which decreases to 1/10 of its axial intensity at a radius of 2 cm. The distribution was also measured as a function of time and no appreciable change in shape occurred during the first four msec. Also a collimated scintillation probe was inserted perpendicular to the axis midway between the mirrors to measure the electron flux diffusing radially outward. No detectable signal was observed. Within the accuracy of the data these experimental results are consistent with a small radial diffusion rate as predicted by scattering theory.[1,2]

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] L. Spitzer, *Physics of Fully Ionized Gases* (Interscience Publishers, Inc., New York, 1956), p. 38.
[2] C. Longmire and M. Rosenbluth, Phys. Rev. **103**, 507 (1956).

**B10. Studies of Plasma Confinement in a Mirror Machine: Effect of Impurities and Other Perturbations.*** R. F. POST, R. E. ELLIS, AND W. PERKINS, *Lawrence Radiation Laboratory, Livermore.*—An empirical study has been made of the effects of introducing controlled perturbations into the confined plasma in the Table Top mirror machine. The following perturbations have been studied: (1) neutral gases (helium or argon) introduced before the compression cycle, (2) mechanical obstacles, such as probes, (3) short bursts of plasma introduced across the confining field during the confinement cycle. The effect of these perturbations gives further insight into the purity, density, spatial extent, and confinement time of the compressed plasma. The confinement time is found to be substantially reduced by the admission of relatively small quantities of a heavy gas, in qualtitative agreement with the expected increase in scattering caused by the impurity gas. The effect of introducing obstacles into the chamber roughly confirms

information on the plasma spatial distirubtion obtained in other ways. The introduction of plasma bursts late in the confinement cycle confirms the existence of a confined plasma and can be used to give some approximate information on its absolute density.

* Work done under the auspices of the U. S. Atomic Energy Commission.

**B11. Experimental Properties of the Magnetic Beach Geometry.*** W. M. HOOKE, F. H. TENNEY, R. M. CLARY, AND T. H. STIX, *Project Matterhorn, Princeton University.*—Experiments have been performed with B-66 Stellarator components temporarily assembled in the geometry of a linear magnetic mirror plasma confinement device. Weak magnetic field regions[1] ("magnetic beaches") exist between the end mirrors and the central rf induction coil. At high rf power levels a high degree of ionization is obtained in a deuterium plasma, and the loading of the rf induction coil is consistent with the generation of ion cyclotron waves. The spatial distribution of observed neutrons varies with the magnitude of the confining magnetic field. The variation is consistent with neutron production in that region of the device where the impressed rf frequency equals the local ion cyclotron frequency.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] T. H. Stix, Phys. Fluids 1, 380 (1958).

**B12. Direct Electrical Excitation of Ion Cyclotron Waves.*** E. CHAMBERS AND H. P. FURTH, *Lawrence Radiation Laboratory, Livermore.*—An ingenious scheme for inductive excitation of ion cyclotron waves has been devised by Stix[1] for use in stellarator heating. In a mirror machine, ion cyclotron waves can be excited directly by means of an oscillating radial electric field between concentric ring electrodes at one end of the machine. The mirror geometry furthermore provides a natural "magnetic beach"[1] for damping. If the magnetic field in the central region corresponds to ion cyclotron resonance for the applied wave, the wave will pass readily through the mirror region but reach zero phase velocity at the center. The main problem with this method is the technical one of insulation between the rf electrodes. A scheme which is being tried experimentally makes use of a PIG discharge between a ring cathode and two (inner and outer) ring anodes. The rf is applied between the anodes, and the cathode sheath provides insulation, since it has a higher impedance than the PIG, seen as a coaxial transmission line. Present experiments demonstrate the basic features, but the azimuthal inhomogeneity of the PIG has prevented quantitative confirmation of the theory.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] T. H. Stix, Phys. Fluids 1, 308 (1958).

**B13. Combination of Axial Magnetic Field Heating and Cusp Confinement.** DAVID FINKELSTEIN, SAMUEL KOSLOV, KENNETH C. ROGERS, AND GEORGE SCHMIDT, *Stevens Institute of Technology.*—A compression heating and linear injection cusp experiment (CHALICE) is underway to combine the stable confinement of the cusp geometry with the efficient compression heating of an axial magnetic field. Both the cusp and axial magnetic field are formed with the same pair of coils. After preionization a rapidly rising field compresses the plasma inside two long cylindrical one-turn coils, forming two plasma threads. These coils have a common axis, and opposing currents produce a point of zero field in the plane of symmetry between the coils. The magnetic field pressure increases monotonically from the central point of zero field to the far ends of the coil thus driving the compressed plasma threads into the central region, where they are trapped by a hydromagnetic collision. In the central low-field region the hot, high-pressure plasma expands to a cusp-shaped equilibrium, cooling significantly less than adiabatically. This achieves higher final temperatures than by using the cusp field itself for compression.

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## THURSDAY AFTERNOON AT 2:00

### Spanagel Hall

### (M. N. ROSENBLUTH presiding)

**C1. Transport Properties of a Fully Ionized Gas.** M. R. C. MCDOWELL,* *Royal Holloway College, University of London* (introduced by E. W. McDaniel).—The radial equation for the quantal scattering of slow electrons by a screened coulomb field is solved numerically for a wide range of electron densities $N_e$ and temperatures $T_e$, $10^8 \leq N_e \leq 10^{18}$; $10^4 \leq T_e \leq 10^7$(°K). The resulting phase shifts are compared with those obtained from Massey-Mohn, Born, and Schwinger approximations. The diffusion and viscosity cross sections $Q_d$ and $Q_\eta$ are then evaluated in each of these ways, and used to obtain electric and thermal conductivities. Numerical results presently available include the Born and Massey-Mohr approximations to $Q_d$ and $Q_\eta$. These are compared with the classical results of Spitzer[1] and Liboff[2]; which appear to overestimate by some 20% at high densities. The analysis is also carried out for Thiemer and Hoffmans'[3] modified screened coulomb potential. The discrepancy between their results and those of previous workers is due to their adoption of a nearest neighbor, rather than a Debye, approximation to the screening parameter.

* Present address: Physics Department, Georgia Tech., Atlanta 13, Georgia.
[1] L. Spitzer, *Physics of Fully Ionized Gases* (Interscience Publishers, Inc., New York, 1956).
[2] R. L. Liboff, Phys. Fluids 2, 40, (1959).
[3] O. Thiemer and H. Hoffman, Astrophys. J. 129, 224 (1959).

**C2. Self-Consistent Field and Motion of Electrons which Slow Down in a Uniform Impressed Magnetic Field.** LEWI TONKS, *Lawrence Radiation Laboratory, Livermore.*—The solution of the problem of the self-consistent motion of relativistic electrons circulating, slowing down, and scattering in a uniform impressed magnetic field—the Astron *E*-layer problem—has progressed to where the slowing down has been handled. Monoenergetic electrons injected (conceptually) with zero radial speed and identical axial speed uniformly over the service of an infinite cylinder, are assumed to lose energy (to a plasma) at a rate inversely proportional to their instantaneous speed. In circulating about the axis of symmetry they form the *E*-layer. The controlling parameters are the initial total momentum $p$ of the electrons expressed in units of $m_0c$, the ratio $G$ of injection-cylinder radius to initial gyration radius in the undistorted vacuum field and a quantity $S$ which is proportional to the product of the electron life and the number injected per second for each classical-electron diameter ($5.60\times10^{-13}$ cm) of axial length. The results of the calculation follow qualitatively those for simpler cases. For fixed $p$ and $G$, increasing $S$ causes field reversal first at the axis and then at increasing distances from it. $G$, however, can be somewhat less than 2 and still have this occur.

**C3. Velocity Scattering in an Ensemble with Coulomb Interaction.** G. ECKER* AND D. VOSLAMBER, *Institut fur Theoretische Physik, Universitat Bonn.*—The application of the Fokker-Plank equation to describe an ensemble with long range interaction requires the knowledge of the momenta $\langle \Delta V_1 \cdots \Delta V_K \rangle_{Av}$ of velocity scattering. In particular the second momentum $\langle \Delta V_1 \cdots \Delta V_K \rangle_{Av}$ is of interest. As in most of the earlier work, our approach uses the stochastic superposition of the contributions of the individual field particles, but it makes use of a more accurate description of the motion of these field particles. We find, that, in general the probability distribution for $\Delta V$ will show deviations from the commonly used gauss function. The well-known logarithmic divergence of the second order momentum disappears, even for a one-component ensemble without Debye screening. Comparison with the results of the earlier "cutoff" theories for the case of a two-component ensemble (plasma) shows good agreement with the theories using "Debye cutoff" as suggested by Bohm and Aller, and Spitzer, Routhly, and Cohn. Only at lower values of $T/n^{\frac{1}{3}}$ our our new results appear to be slightly smaller. However, for the one-component ensemble (space charge region, star ensemble) the second momentum appears to be very much larger, than calculated from the "nearest neighbor cutoff."

* Presently at U. S. Naval Postgraduate School, Monterey and Lawrence Radiation Laboratory, Berkeley, California.

**C4. Radiation Limited Self-Constricted Streams.** J. D. LAWSON,* *Stanford University.*—In self-constricted streams the quantity $\nu = Nr_0$, the product of the line density of electrons and the classical electron radius, is a significant parameter. If $v_d$ and $v_t$ are the rms drift and transverse electron velocities, then the Bennett pinch relation $I^2 = 2NkT$ may be written as $\nu/\gamma \approx (v_t/v_d)^2$ where $\gamma = (\text{total energy of electron})/m_0c^2$. For pinched plasmas $\nu \gg 1$, and for neutralized electron beams $\nu \ll 1$. If there is an electric field along the stream, then by considering energy and momentum balance a "steady-state" condition in which the energy radiated is equal to that gained from the electric field may be obtained. Two solutions have been found, one by Pease[1] and Braginsky[2] valid when $\nu \gg 1$, and one by Budker,[3] valid when $\nu \ll 1$, in which the energy is carried away by bremsstrahlung and by synchrotron radiation, respectively. A simple unified treatment of the two cases will be given, yielding relations between $\nu$, $v_d$, the stream radius and the electric field.

* On leave from Atomic Energy Research Establishment, Harwell, England.
[1] R. S. Pease, Proc. Phys. Soc. (London) **B70**, 11 (1957).
[2] S. I. Braginsky, Soviet Physics, J.E.T.P. 6(33), 494 (1958).
[3] G. I. Budker, Atomnaya Energiya **5**, 9 (1956).

**C5. Velocity Distribution of Plasma Electrons in Dynamic Equilibrium.** C. B. SHAW, JR., *Hughes Aircraft Company.*—The standard calculation of the rate at which a system of hot ions and somewhat cooler electrons approaches thermal equilibrium assumes that each species has a Maxwellian velocity distribution although the kinetic temperatures differ. The assumption can be supported by comparison of electron and ion self-collision times and the electron-ion equipartition time as thus computed.[1] However, this standard assumption implies a rate of change for the electron distribution function which, particularly for "slow" electrons (having speed less than the mean ion speed) can be substantially smaller than the rate calculated for initially Maxwellian distributions using a previously reported formulation of the coupled Fokker-Planck equations for the system.[2] Setting the rate equal to zero to simulate a substantial reduction from the initial value, the Fokker-Planck equation was solved for the non-Maxwellian velocity distribution in this condition of "dynamic equilibrium." The extent to which the number of slow electrons is depleted below the Maxwellian level, and the effect of depletion on the ion cooling rate will be discussed.

[1] L. Spitzer, Jr., *Physics of Fully Ionized Gases* (Interscience Publishers, Inc., New York, 1956), Chap. 5.
[2] C. B. Shaw, Jr., Bull. Am. Phys. Soc. Ser. II, **4**, 363 (1959).

**C6. Numerical Solution of the Fokker-Planck Equation for a Plasma.*** W. HECKROTTE AND J. KILLEEN, *Lawrence Radiation Laboratory, Livermore.*—A suitable theoretical description of the interaction of the ions and electrons in a plasma among themselves is given by the Fokker-Planck equation.[1] Some numerical solutions to the Fokker-Planck equation for one species of particles have been previously obtained.[2] An IBM 709 code, called Dion, will be described which considers two species of particles. In this code it is assumed that the particles have an isotropic velocity distribution. A variable mesh in the energy variable is used. In replacing partial differential equations by difference equations a severe restriction is imposed on the size of the time step that can be used if an explicit differencing scheme is used. To avoid this difficulty, an implicit differencing scheme has been used in the code to be described. The results for the energy transfer to cold electrons by hot ions will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] M. N. Rosenbluth, W. M. MacDonald, and D. L. Judd, Phys. Rev. **107**, 1 (1957).
[2] W. M. MacDonald, M. N. Rosenbluth, and W. Chuck, Phys. Rev. **107**, 350 (1957).

**C7. Irreversibility in Bogolubov's Kinetic Equation for a Spatially Homogeneous Plasma.*** ANDREW LENARD, *Project Matterhorn, Princeton University.*—Bogolubov has derived a kinetic equation for a spatially homogeneous plasma.[1] In this equation the time derivative of the velocity distribution function is given in terms of the pair distribution function, while the latter is determined in terms of the former by a time independent integral equation. This integral equation is solved and it is shown that the resulting kinetic equation has a collision term of the Fokker-Planck type. Furthermore, irreversible relaxation to equilibrium can be shown by proving the $H$ theorem. It can also be shown that only a proper choice of contour of complex integration in the original integral equation leads to relaxation to equilibrium from arbitrary initial distributions.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] N. N. Bogolubov, *Problems of Dynamical Theory in Statistical Physics* (Moscow, 1946), in Russian; also English translation by E. K. Gora. ASTIA Doc. No. AD-213317, Air Force Cambridge Research Center (1959).

**C8. Generalizations of the Saha Equations.*** EDMOND M. DEWAN,† *Air Force Cambridge Research Center.*—The Saha equation which relates temperature to ion densities is some times used under circumstances which do not justify the assumptions of thermodynamic equilibrium upon which it is based. Astronomers have therefore made generalizations of this equation, but, unfortunately, they assume thermodynamic equilibrium energy distributions for the particles and the radiation field even though these may be at different temperatures. It is therefore interesting to know how the nonequilibrium *steady-state* energy distributions affect the ionization densities. In the present treatment, a general expression relating ion densities to the radiation and particle energy distributions is obtained. This equation reduces to Saha's equation in the limit of thermal equilibrium and gives numerical results in good agreement with other work based on entirely different considerations, thus providing a good check. We find that under certain conditions, one would expect results which differ enormously from those predicted by the Saha equation.

* Supported by the Office of Naval Research.
† Based on a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Yale University.

**C9. Configuration of a Fully Ionized Plasma in an Axially Symmetric External Magnetic Field.*** SYLVAN KATZ, *University of California, Los Angeles.*—The first three moments of the Boltzmann equations for the ions and electrons, together with the Maxwellian equations, form our fundamental system. These equations are written in a special orthogonal curvilinear system of coordinates in which one of the coordinate curves coincides with the external magnetic field. Performing a perturbation expansion for a low $\beta$ adiabatic plasma, a system of zero order equations is obtained. This system is incomplete in that there are more unknowns than equations serving for their determination. When the diagonal terms of the divergence of the zero order heat flux tensor are taken to vanish a determinate system of equations is obtained and solved. This is a fairly restricted solution for the plasma. Less restricted solutions are obtained by arbitrarily specifying the distribution of the density and of the perpendicular component of the pressure. Graphical presentation of the results will be given for a specific mirror geometry.

* Supported by the U. S. Atomic Energy Commission through the Lawrence Radiation Laboratory, Berkeley and Livermore.

**C10. Equilibrium Configuration of a Plasma in the Guiding Center Limit.** ALAN OPPENHEIM, *Institute of Mathematical Sciences, New York University.*—We treat the hydromagnetic equilibrium of a completely ionized gas in an axially symmetric magnetic field, using a nonscalar pressure tensor which arises from the guiding center approximation. The assumption of a long thin field shape, the neglect of field line curvature, and specialization of the distribution function lead to a tractable problem for the low $\beta$ limit and an expansion procedure in the neighborhood of low $\beta$. We assume that at the center plane the component of the pressure tensor perpendicular to the magnetic field lines varies linearly with the magnetic flux density. The shape of the plasma boundary as well as the values of the magnetic field and pressure at the relevant boundary points are arbitrary parameters for this problem.

**C11. A Variational Principle for Equilibria from the Particle Point of View.*** RUSSEL M. KULSRUD, *Project Matterhorn, Princeton University.*—The self-consistent equations describing the equilibrium of a plasma from a particle point of view are written down in the limit of small Larmor radius according to the theory of Chew, Goldberger, and Low. Collisions are neglected entirely. The equilibrium is discussed in the case of toroidal geometry and shown to have magnetic surfaces. The Boltzmann function depends only on the magnetic moment, the energy and the magnetic surface of a particle. A variational principle is derived in which the full system of self-consistent equations is equivalent to the energy being a stationary value over all configurations subject to the following constraints: Magnetic surfaces exist, $f$ is a function only of energy, magnetic moment, and magnetic surface which is given by demanding $f$ be a prescribed function of magnetic moment, magnetic surface, and an adiabatic invariant which is a generalization of the usual longitudinal invariant to the case of magnetic surfaces. Finally, the electric field $E$ is the gradient of a single valued scalar. This variational principle yields automatically charge neutrality. By means of it some idea may be obtained as to possible equilibria which may exist.

* Work performed under auspices of U. S. Atomic Energy Commission.

**C12. Some Hydromagnetic Equilibrium. II.*** JOHN M. GREENE AND JOHN L. JOHNSON,† *Project Matterhorn, Princeton University.*—Further hydromagnetic equilibria[1] for systems which differ little from a zero pressure uniform axial magnetic field are presented. The perturbations from this equilibrium are the presence of particle pressure, axial current, curvature of the system, and multipolar fields. Solutions are given for several cases where the material pressure is proportional to $\chi$, where $\chi$ is the flux the short way inside a magnetic surface, up to a bounding magnetic surface and zero outside, and the axial current distribution is simply related to $\chi$ inside this surface and zero outside. It is shown that the shape of the magnetic surfaces is essentially independent of the material pressure if a particular magnetic field perpendicular to the plane of the torus is applied by external currents, whereas the shape of the surfaces changes with pressure if no such field is applied. Calculations of the net current on each magnetic surface, the rotational transform associated with each surface, and the vacuum field external to the plasma are given.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On loan from Westinghouse Electric Corporation, Atomic Power Department.
[1] Greene, Johnson, and Koenig, Bull. Am. Phys. Soc. Ser. II, 4, 248 (1959).

**C13. Nonconfinement of an Assembly of Charged Particles.*** M. BERNSTEIN, L. N. ZADOFF, AND JULIAN REINHEIMER, *Republic Aviation Corporation, Missile Systems Division.*—The impossibility of confinement of an isolated plasma by a magnetic field associated with internal or surface currents only can be shown by an extension of the Chandrasekhar-Fermi virial therorem. By considering the plasma as an assembly of charged particles, this conclusion has been corroborated. Plasma confinement in the two dimensional linear pinch has been previously demonstrated by use of a particular nonequilibirum stationary distribution.[1] If the plasma is in a stationary state, the distribution function is a function of the constants of the motion only. The particle densities are functions of the magnetic field such that confinement depends on the boundary conditions on the field at infinity. In a three dimensional configuration the boundary conditions on the magnetic field are such that confinement is impossible.

* This work supported by the Air Force Special Weapons Center.
[1] Erich Weibel, Phys. Fluids 2, 52 (1959).

**C14. Interpretation of Certain Experiments on rf Confinement.** P. A. STURROCK, *Stanford University.*—It has been found experimentally that certain configurations of electromagnetic field in the frequency range 1–10 Mcps lead to contraction of a plasma column. This effect has the appearance of "rf confinement," but this interpretation is difficult to sustain, for reasons to be explained.

Investigation of the electric-field pattern necessary to explain observed plasma configurations leads one to explain these experiments in terms of "pseudoconfinement," Surface charges build up on the inner wall of the glass tube in such a way that electrons experience a radially inward force over almost all of the surface of the plasma almost all of the time; ions therefore experience an outward force almost everywhere almost all of the time. The effect of the rf electric field is therefore to promote formation of a high-voltage sheath separating the plasma from the glass tube. This interpretation appears to be fully compatible with observations on confinement so far made with various electric-field patterns. Further evidence in support of this interpretation will be offered.

**C15. Densities of Particles Trapped by the Geomagnetic Field.*** J. KILLEEN AND G. BOER, *Lawrence Radiation Laboratory, Livermore.*—Given an arbitrary source density distribution, $n_0(r,\theta,\phi)$ in particles/cm$^3$. it is important to know the density of mirror points and the trapped particle density along the earth's field lines. An IBM 709 code, called APPLE, is described which calculates these densities. The earth's magnetic field is taken to be a dipole so the coordinates for $n_0$ are the distance from the dipole center, the geomagnetic colatitude, and the geomagnetic longitude. From the given source distribution a source density along field lines, $n_0(\theta_0,\theta,\phi)$ is calculated where $\theta_0$ parametizes the field line. The density of mirror

points is then calculated assuming the velocities are isotropically distributed and that the magnetic moment is a constant of the motion. From this density distribution the trapped particle density is calculated. In an earlier code the trapped particle density was calculated directly from the source distribution. The advantage of the present course is that lifetime calculations involving scattering of the particles by the atmosphere can be used to modify the mirror point density. Then a trapped particle density can be calculated which includes these losses.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

## THURSDAY AFTERNOON AT 2:00

### King Hall

### (N. L. OLESON presiding)

**D1. Energetic Particle Loss in DCX.** C. F. BARNETT, G. R. HASTE, AND J. A. RAY, *Oak Ridge National Laboratory.*—Neutral hydrogen particles escaping the trapped plasma in DCX have been measured using detectors sensitive to H particles of more than 50 kev. Particle detectors placed lengthwise and azimuthally enabled the surface loss by charge exchange to be measured everywhere except the ends. The lengthwise distribution was peaked at the midplane, while the azimuthal distribution displayed a lobe in a direction of particles being neutralized in the arc. At $10^{-6}$ mm Hg neutralization in the residual gas accounts for about 55% and neutralization in the arc accounts for about 30% of the initial input particles; other mechanisms, such as mirror losses, are relatively unimportant under these conditions. The extent of arc loss depends on the running condition of the arc. Containment times of 5-6 msec and microwave studies suggest a particle density of the order of $10^{10}$ particles/cc at $10^{-6}$ mm Hg.

**D2. Orbit Precession in DCX.** J. L. DUNLAP, T. K. FOWLER, AND R. S. EDWARDS, *Oak Ridge National Laboratory.*—It appeared that, in DCX, undesirable effects of the carbon arc on trapped ions could be reduced by deliberately causing the ions to precess and miss the arc a fraction of the time. The containment properties of DCX restrict consideration to those precession orbits for which $X < r_0$, where $X$ is the displacement of the guiding center of the precessing ion from the symmetry axis and $r_0$ is the radius of the symmetric orbit. For such precession orbits a precession factor of decrease $g$ in the amount of time the trapped ion spends inside the arc was calculated.

A precession run was made in DCX utilizing an orbit which, on the basis of the half-inch diameter of the arc core and idealized ion orbits, would be characterized by a $g$ value of approximately 0.1. The plasma containment times for this run showed no significant increase over runs in which precession was not deliberately introduced. The results suggest that the effective charge exchange diameter of the arc is considerably larger than one-half inch and/or that the ion orbits for runs without deliberate precession are in fact already distorted from the idealized configuration.

**D3. Alkali Vapor Plasmas.** H. S. ROBERTSON AND M. A. HAKEEM, *University of Miami.*—The positive column plasmas of dc glow discharges in cesium and rubidium have been examined over a wide range of pressure and current density. Moving or standing striations, which are almost always evident in these plasmas,[1] have not been found. This result is in agreement with the thesis that moving striations are associated with metastable atomic states,[2] since the alkali neutral atoms do not have metastable levels. It is not a conclusive result, however, since the experimental work is not yet exhaustive, and since there may be other reasons for the absence of moving striations in the alkali vapors.

[1] T. M. Donahue, and G. H. Dieke, Phys. Rev. **81**, 248 (1951).
[2] Harry S. Robertson, Phys. Rev. **105**, 368 (1957).

**D4. Velocity Analyzer Study of the Neidigh Pressure Gradient Arc.** WILLIAM B. PARDO AND HARRY S. ROBERTSON, *University of Miami and Oak Ridge National Laboratory.*—A preliminary study of the Neidigh pressure gradient arc has been made with an ion velocity analyzer utilizing crossed electric and magnetic fields. The dependence of ion velocities on various arc parameters such as cathode potential, filament current, gas flow rate, chamber pressure, and magnetic field intensity have been measured. The velocity analyzer yields clear, reproducible data of a kind which supports and amplifies the experimental work of Neidigh and Weaver.[1] Characteristically a sharply peaked collector current was observed as a function of the applied electric field. The collector signal is a maximum at a velocity which is independent of magnetic field intensity when other arc conditions are fixed. Ion energies were observed several times larger than would be expected from the applied arc voltage. It appears that the ion accelerating mechanism is associated with the pressure gradient, rather than with the magnetic field.

[1] R. V. Neidigh and C. H. Weaver, "Effect of an applied pressure gradient on a magnetically collimated arc," Proc. Second Conf. Peaceful Uses Atomic Energy, Geneva, 1958, paper P/2396.

**D5. P-4—A Steady-State Plasma System.*** A. L. GARDNER, L. S. HALL, AND D. E. EDWARDS,† *Lawrence Radiation Laboratory, Livermore.*—A system is described which produces a steady-state helium plasma with greater than 95% ionization. The primary plasma is generated in a modified PIG discharge which runs at 70–80 amp and 150–175 v. This plasma then diffuses along a magnetic field ($B \sim 1$ kilogauss) through a region where neutral particles are preferentially removed. In the downstream region, microwave measurements reveal a maximum electron density of about $2 \times 10^{13}$ electrons/cm$^3$ and spectroscopic measurements (described in another paper) show ion temperatures up to 8 ev. The plasma in this region is reasonably quiescent: essentially no macroscopic currents flow since the surrounding walls are of glass or quartz and no electric fields are deliberately impressed. Probe measurements are described in another paper.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Cornell University, Ithaca, New York.

**D6. Probe Measurements in P-4.*** N. L. OLESON† AND D. M. GALL,‡ *Lawrence Radiation Laboratory, Livermore.*—Probes were used in the highly ionized steady-state plasma of the P-4 system for measurements of electron density, electron temperature, space potential and floating potential. These cylindrical tungsten probes of 4 to 25 mils diam and ¼ in. length could be moved radially into the discharge. Both point by point and voltage sweep methods were employed, the latter permitting further penetration into the discharge before melting of the probes occurred. The space potential and floating potential increase with radial distance from the center, whereas the electron density decreases with this distance. At the dis-

tance of closest approach to the center (~9 mm) the electron density of $8\times10^{12}$ per cc agrees with microwave measurements. Langmuir plots indicate a single Maxwellian electron energy distribution for the outermost regions of the plasma, increasing from 4.5 to 7 ev with decreasing distance. Closer to the center an additional faster group appears, as is to be expected from the nature of the P-4 system.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† U. S. Naval Postgraduate School, Monterey, California.
‡ Lieutenant, U. S. Navy, U. S. Naval Postgraduate School, Monterey, California, (assigned to LRL).

**D7. Spectroscopic Measurements in P-4.*** WILLIAM L. BARR AND RAYMOND L. KELLY,† *Lawrence Radiation Laboratory, Livermore.*—The radiation from P-4 was studied from the vacuum ultraviolet up to the visible region. All 232 spectral lines which were positively identified arose from the various states of ionization of: He, C, N, and O. Only He was deliberately admitted into the system. The existence of some high energy electrons was established by the presence of $O^{4+}$ and $N^{4+}$ in the plasma. Doppler widths of the $He^+$ line at 4686 A corresponding to ion temperatures up to 8 ev were observed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Stanford Research Institute, Menlo Park, California.

**D8. Cesium Plasma.*** R. B. HALL AND G. BEKEFI, *Massachusetts Institute of Technology.*—Following a suggestion of N. Rynn, a steady-state plasma of high degree of ionization was produced by directing a beam of cesium atoms at a hot tungsten surface and removing the ions thus produced by a voltage applied between this surface and a second electrode. A dc magnetic field of 1200–2400 gauss reduced the diffusion loss of ions to the walls of the glass envelope. A section of the envelope close to the cesium oven was maintained at −78°C and reduced the vapor pressure in the rest of the system to less than $10^{-6}$ mm Hg. An ion current density of 5 ma $cm^{-2}$ was obtained with a dc field of 4 v $cm^{-1}$ and at a filament temperature of 2100°C. The cesium oven, with an aperture of 0.17 cm diam, was kept at 250°C. From the current-voltage characteristic, the ion density was estimated to be between $2\times10^{10}$ $cm^{-3}$ and $3\times10^{11}$ $cm^{-3}$. The electron density calculated from the frequency shift of a microwave cavity was approximately $5\times10^{10}$ $cm^{-3}$. Thus the degree of ionization was in excess of 50%.

* Supported in part by the U. S. Army, the U. S. Air Force, the U. S. Navy, and the U. S. Atomic Energy Commission.

**D9. Apparent Enhanced Diffusion in Plasma in a Magnetic Field.*** T. K. ALLEN,† GEORGE A. PAULIKAS,‡ AND ROBERT V. PYLE, *Lawrence Radiation Laboratory, Berkeley.*—The behavior of the glow-discharge positive column in a longitudinal magnetic field agrees well with theory up to a critical value. At higher values of magnetic field the longitudinal electric field is appreciably higher than expected[1] and the associated increase in electrical noise has led to the suggestion of enhanced charged particle losses by the mechanism of "drain diffusion."[1] Extension of these experiments shows a relation between the enhanced losses and a marked unstable constriction of the luminous plasma column. Further information on this constricted column, its helical nature and rotation, and associated properties will be reported.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Visiting Lawrence Radiation Laboratory from AERE, Harwell.
‡ National Science Foundation Predoctoral Fellow.
[1] B. Lehnert, Proc. Second Intern. Conf. Peaceful Uses Atomic Energy, Geneva, 1958, **32**, 349 (1958).

**D10. Some Studies of Current Flow and Boundary Effects in Homopolar III.*** WILLIAM R. BAKER, ALEXANDER BRATENAHL, AND WULF B. KUNKEL, *Lawrence Radiation Laboratory, Berkeley.*—Homopolar III is the latest of a series of rotating-plasma devices under study at LRL Berkeley. Like its predecessors, it achieves a high degree of ionization and high rotational velocities through the passage of 50 to 100 kamp radially across an axial magnetic field. In the earlier devices, the insulators were perpendicular to the axis of rotation. Calculations show that the steady state is likely to be controlled by currents flowing along insulators.[1] In this device the insulators are parallel to the axis of rotation, and full use is made of the centrifugal force to drive the plasma away from the insulators. An evaluation of the gain of the system will be presented. The current distribution is known in considerable detail through the use of "current buttons," that is, small isolated portions of the outer electrode. Acoustic, magnetic, and voltage probes, and a new type of probe based on magnetoaerodynamic principles have aided this evaluation.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Baker, Bratenahl, DeSilva, and Kunkel, "Viscous effects in highly ionized rotating plasmas," *Proceedings of the Fourth International Conference on Ionization Phenomena in Gases, Uppsala, 1959* (North-Holland Publishing Company, Amsterdam, Netherlands, 1959).

**D11. "Free Wheeling" Operation of a Rotating Plasma.*** D. A. BAKER AND J. E. HAMMEL, *Los Alamos Scientific Laboratory.*—The energy in a plasma rotating in crossed electric and magnetic fields such as in Ixion[1] (The Los Alamos Rotating Plasma Experiment) will in general be contained in ordered rotational motion as well as random-phase Larmor motion. Experiments which measured the total energy have been reported previously.[2] A technique has been developed which allows the energizing capacitor bank to be disconnected from Ixion at any chosen time $t_D$ after the plasma is rotating. The observation on the freely rotating plasma show that Ixion can be represented by an equivalent circuit consisting of a capacitor with a parallel resistor. The capacity, resistance, and rotational energy were determined as a function of time and axial magnetic field. The natural decay of the freely rotating plasma was nearly independent of the applied magnetic field and $t_D$, although the capacitance and resistance varied over orders of magnitude. This fact suggests that the decay of the rotating plasma is dominated by interactions with neutrals. The plasma diamagnetism was also observed during this operation.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Keith Boyer, TID-7558 (1959), p. 140.
[2] D. A. Baker, F. L. Ribe, Bull. Am. Phys. Soc. Ser. II, **4**, 248 (1959).

**D12. Microwave Radiation from Stellarators.*** ROBERT MOTLEY, CLAUDE LUSTIG, AND STEVEN SANDERS, *Project Matterhorn, Princeton University.*—The properties of microwave radiation emitted in helium and hydrogen discharges in the B-3 stellarator have been investigated. Measurements of the radiation entering microwave horn antennas viewing the plasma perpendicularly and longitudinally have been made using superheterodyne receivers tuned to 10, 27, 35, and 70 kMc.

Two types of radiation have been found: (I) a background noise the intensity of which exceeds by two orders of magnitude the blackbody level calculated from the conductivity; and (II) bursts of radiation which under some conditions exceed the blackbody level by $10^5$.[1] Type I radiation persists for 20 msec following the disappearance of the main body of the plasma. Its characteristics include a magnetic field dependence which suggests a synchrotron origin, and an absence of linear polarization. Type II radiation is most intense near the electron cyclotron and plasma frequencies and disappears soon after complete ionization.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. A. Heald, *Proceedings of Conference on Controlled Thermonuclear Reactions*, AEC Report TID-7520 (1956).

**D13. Discharge Cleanup in the Etude Stellarator.*** M. S. JONES, JR., AND L. G. SMITH, *Project Matterhorn, Princeton*

*University.*—It is observed that repeated ohmic heating discharges in the ETUDE Stellarator result in a reduction in impurity ion concentration. After an initial rapid "cleanup," the rate becomes much slower with increased running time. The carbon, nitrogen and oxygen impurity concentration levels in a helium discharge, as determined by mass and optical spectrographic measurements, is of the order of 0.1% under the cleanest conditions obtained. The principal effect resulting from the cleanup in the gross stellarator discharge characteristics is a reduction in the apparent confinement time of the plasma during the pumpout instability.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**D14. Interferometric Measurement of Plasma Rotation in the B-1 Stellarator.*** J. G. HIRSCHBERG AND EINAR HINNOV, *Project Matterhorn, Princeton University.*—A Fabry-Perot interferometer coupled with a prism spectrometer is employed to establish and measure rotation of the plasma in the B-1 stellarator by means of the Doppler effect. Shifts of the order of 0.30 A corresponding to an angular rotational velocity of $1\times10^6$ radians/sec were found, using the light of singly ionized helium in a Kruskal-limited discharge. Neutral helium, on the other hand, showed no shift, indicating no rotation. The sense of the rotation is that of a left-handed screw advancing in the direction of the magnetic field.

* Supported by the U. S. Atomic Energy Commission.

**D15. Evidence for Hydromagnetic Kink Instability in the B-1 Stellarator. I.*** W. BERNSTEIN, A. Z. KRANZ, AND F. TENNEY, *Project Matterhorn, Princeton University.*—Regular oscillations from 30 to 200 kc have been observed in the B-1 Stellarator[1] during ohmic heating discharges in helium. The oscillations were observed with magnetic probes, a Langmuir probe, and an optical system defining a narrow slit at the discharge oriented parallel to the confining field. Oscillations observed at two ports, separated by half the machine length, bear a definite phase relation to one another indicating the entire plasma is coherently involved. For a given confining field, the oscillations seem only to occur for certain ranges of the discharge current. Furthermore, the oscillations occurring in each of these current ranges seem to be associated with a characteristic geometrical distortion of the plasma column. Each distortion or mode is characterized by the number of phase reversals observed optically during a scan transverse to the confining field. We have observed modes characterized by 1, 3, 4, and 5 phase reversals. The $m=1$ mode is associated with the "Kruskal limit," the "higher modes" occurring for lower values of the discharge current. The oscillations have been observed to persist for several hundred $\mu$sec indicating considerable stability.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

[1] T. Coor, S. P. Cunningham, R. A. Ellis, M. A. Heald, and A. Z. Kranz, Phys. Fluids 1, 411 (1958).

## FRIDAY MORNING AT 9:00

## Spanagel Hall

## (E. A. FRIEMAN presiding)

**E1. Production of a Plasma by Shock Waves.** MARVIN L. WHITE, *Boulder Laboratories of the National Bureau of Standards.*—The theory for the formation of a blast wave by G. I. Taylor (1950) has been extended to include the dissipation of energy through ionization. While Taylor's theory can account for the expansion of the "ball of fire" in an atomic explosion where the kinetic energy of the material medium is dominant, ionization effects are expected to appreciably retard the shock for the intermediate case. Taylor's theory is based on the so-called similarity assumption, resulting in a variables separable solution. In present theory, the simplest departures from the similarity principle are assumed. The variables separable solution is the $R$-asymptotic solution of our more general case ($R$ is the radius of the spherical or cylindrical shock). It is shown that the numerical integrations by Taylor for the profile behind the shock suffice for our treatment as a consequence of (1) the model and, (2) the conservation of the total energy in an behind the shock. For a given energy input, the theory predicts the density, temperature, pressure, and degree of ionization in and behind the shock as well as the shock velocity; it is directly applicable to the formation of a plasma by laboratory-produced shock waves.

**E2. Shock Waves in a Moderately Hot Plasma.** BURTON D. FRIED, *Space Technology Laboratories.*—For a plasma with a density of the order of $10^{16}$ cm$^{-3}$ and a temperature of 1 to 100 ev, ions accelerated by a fast magnetic "piston" (piston velocity $10^7$ to $10^8$ cm/sec) have a relatively long mean free path (mfp) whereas the electrons have a very short mfp. In these circumstances, it is shown that the piston may produce a shock wave whose thickness is of the order of the electron mfp, the ion motion being influenced chiefly by the charge separation electrostatic field which develops at the shock front. For very high piston velocities, the appropriate Rankine-Hugoniot equations have three solutions, differing from one another in the distribution of trapped ions. In cylindrical geometry, a converging shock will increase in strength as it approaches the center, just as in the classical case. In contrast to the plane case, the region of nonzero electric field is then not confined to the shock front, but a similarity solution for this case can be found. This kind of shock may account for the very fast converging waves seen by Heflinger and Leonard[1] and for the high conductivity implied by their observations of trapped flux.

[1] L. O. Heflinger and S. L. Leonard, Bull. Am. Phys. Soc. Ser. II, 5, 323, paper J3 (1960).

**E3. On Certain Properties of Hydromagnetic Shocks.*** W. B. ERICSON, *Grumman Aircraft Engineering Corporation* AND J. BAZER, *New York University, Institute of Mathematical Sciences.*—Four basic properties of stationary planar, nonrelativistic, hydromagnetic shocks are discussed and rigorous proofs presented. These properties are: ($P_1$) the specific entropy behind a hydromagnetic shock exceeds that ahead, if and only if, the shock is compressive; ($P_2$) the specific entropy behind a compressive shock varies in the same sense as the mass flux; ($P_3$) in the region behind (compressive) fast shocks the fast disturbance speed is greater than the normally directed fluid velocity relative to the shock; ($P_4$) in the region behind (compressive) slow shocks, the slow disturbance speed may be less than, equal to, or greater than the normally directed fluid velocity relative to the shock. The equality holds when the specific entropy and the mass flux assume their maximum values. In these statements the state in front is assumed fixed and attention is focused on the variation of the state behind with an appropriate shock strength parameter. The proof of

$P_1$ is designed especially to cover the case of the slow shock where the dependence of the state behind on the "natural" shock-strength parameters is nonmonotonic.

* Supported in part by the Geophysics Research Directorate of the Air Research and Development Command.

**E4. Magnetohydrodynamic Shock Wave in a Collision-Free Plasma.*** H. E. PETSCHEK AND A. KANTROWITZ, *Avco-Everett Research Laboratory.*—The dissipative mechanisms associated with the shock wave are described in terms of a substructure of a random distribution of magnetohydrodynamic waves. These waves are considered to be the fundamental particles of the plasma. All of the thermal energy of the gas is considered to be invested in these relatively few degrees of freedom. The nonlinear interactions between these waves randomizes the distribution of waves. This entropy production may be viewed alternately as the collisions between groups of particles, which for convenience have been described in terms of waves. The mean free path for collisions between waves is estimated and the corresponding shock thickness is determined. Both the shock thickness and its dependence on the Alfven Mach number are in reasonable agreement with experiment.[1]

* This research was supported by the Office of Naval Research.
[1] The previous contributed paper.

**E5. Three-Dimensional Effects in the Electron Diffusion Ahead of Strong Shock Waves.*** H. D. WEYMANN AND A. C. PIPKIN, *University of Maryland.*—The electron density profile in a shock-generated plasma is of interest in may respects. It is determined by the ionization rate and the electron diffusion out of the plasma. While shock tube experiments on the ionization rate investigate an essentially one-dimensional problem, studies of electron diffusion over large distances have to take into account the three-dimensional character of the electric field generated by the charge separation. Results of experimental and theoretical investigations on the nonstationary diffusion of electrons ahead of strong shock waves will be presented.

* Supported in part by the U. S. Air Force Office of Scientific Research.

**E6. Collision-Free Shock.** CATHLEEN S. MORAWETZ, *Institute of Mathematical Sciences, New York University* (introduced by H. Grad).—A self-consistent, collision-free shock profile is determined under certain assumptions made on the state ahead of the shock which is propagating in a direction perpendicular to the magnetic field. Collisionless Boltzmann equations for ions and electrons together with Maxwell's equations are solved to a certain approximation in the limit of small electron-ion mass ratio. For a certain range of parameters a transition has been found from the state in front to a periodic wave train behind.[1] Improved approximations lead to a transition to an almost periodic wave train behind the shock. The bulk of the irreversible transition occurs within a macroscopically narrow region.

[1] C. S. Gardner, H. Goertzel, H. Grad, C. S. Morawetz, M. H. Rose, and H. Rubin, Proc. Second Intern. Conf. Peaceful Uses Atomic Energy, Geneva, 1958, 31, 230 (1958).

**E7. Production of Shock Waves in a Collision-Free Plasma.*** R. M. PATRICK, *Avco-Everett Research Laboratory.*—An experimental investigation of the structure of collision-free magnetohydrodynamic shock waves[1] has been carried out using a magnetic annular shock tube (MAST).[2] The structure has been obtained by measuring the visible and vacuum ultraviolet radiation emitted by the shock heated plasma. The measured shock velocities in hydrogen were between $2\times10^7$ and $4\times10^7$ cm/sec. The plasma density behind these shocks was of the order of $10^{16}$ particles/cm$^3$. These experimental shock speeds and plasma densities were compared to theoretical values obtained assuming the plasma in MAST to be perfectly conducting; complete agreement was obtained within the experimental scatter. The variation of the shock thickness with the Alfven Mach number $M_A$ where $M_A$ is equal to the shock velocity divided by the Alfven velocity in the plasma ahead of the shock was measured for $1.5\leq M_A\leq 3.2$. A steep dependence of the shock thickness on $M_A$ was found with low values of $M_A$ corresponding to thick shocks and high values of $M_A$ corresponding to thin shocks.

* Research supported by the U. S. Air Force.
[1] Kantrowitz, Patrick, and Petschek, *Proceedings of Fourth International Conference on Ionization Phenomena, Uppsala, 1959* (North-Holland Publishing Company, Amsterdam, 1959).
[2] Patrick, Phys. Fluids 2, 589 (1959).

**E8. Attenuation of Hydromagnetic Waves in the Ionosphere.** W. E. FRANCIS AND A. J. DESSLER, *Lockheed Aircraft Corporation, Missiles and Space Division* AND R. KARPLUS, *University of California, Berkeley.*—It has been suggested that the heating due to the dissipation of hydromagnetic waves may be important in the $F$ region of the ionosphere.[1] The propagation constants described by Piddington for hydromagnetic waves must be evaluated for a quantitative description of the hydromagnetic heating problem.[2] A table of propagation constants was calculated for hydromagnetic waves at various altitudes, wave frequencies, and angles of incidence relative to the geomagnetic field. The results will be discussed in relation to the hydromagnetic heating problem.

[1] A. J. Dessler, J. Geophys. Research 64, 397 (1959).
[2] J. H. Piddington, Monthly Notices Roy. Astron. Soc. 116, 314 (1956).

**E9. Measurement of Temperature and Density Ratio across a Strong Shock in Helium.*** WOLFGANG WIESE, HANS F. BERG, AND H. R. GRIEM, *University of Maryland.*—Temperatures and densities have been inferred from line intensity and line profile measurements. A three prism spectrograph equipped with a high speed rotating shutter was used to obtain the spectra emitted from the plasma produced in a magnetic shock tube [T-tube]. First ionization is practically complete for the conditions of this experiment, and the density of heavy particles is therefore almost equal to that of the electrons, which is actually the quantity deduced from the Stark broadening. The results are in agreement with those reported by McLean et al.,[1] i.e., the density is only half or less than that expected from standard shock theory and the temperature is correspondingly larger. An interpretation of this anomaly will be attempted by considering the radiative energy transfer from the plasma behind the shock to the cold gas in front and the effect of magnetic fields.

* Jointly supported by GRDC and Office of Naval Research.
[1] E. A. McLean, C. E. Laneuff, A. C. Kolb, J. E. Milligan, and H. Griem, Bull. Am. Phys. Soc. Ser. II, 4, 118 (1959).

**E10. Some Peculiarities of Shock-Produced Plasmas in Xenon.*** P. GLOERSEN, *General Electric Aerosciences Laboratory.*—The shock tube is generally considered to be a reliable means for the production of plasmas with known properties. A number of phenomena not predicted by existing theory have been encountered during the course of experimentation with shock-produced plasmas in xenon. In addition to the two different types of electrical precursor signals reported earlier,[1] there are indications that the excitation mechanism giving rise to the delayed luminosity behind the shock front is not nearly as simple as has been suggested.[2-4] Four different types of experimental evidence will be presented in support of this contention. Some alternate mechanisms will be suggested. In addition, some observations of the effects of volume impurities on luminosity delay times and of wall impurities on precursor signals will be discussed.

* Based on work performed under the auspices of the U. S. Air Force.
[1] P. Gloersen, Bull. Am. Phys. Soc. Ser. II, 4, 283 (1959).
[2] W. Roth, J. Chem. Phys. 31, 844 (L) (1959).
[3] W. Roth and P. Gloersen, J. Chem. Phys. 29, 820 (1958).
[4] See references 2 and 3 for bibliographies of earlier work.

**E11. Collision of Two Plasma Streams.*** W. E. NEXSEN, W. F. CUMMINS, F. H. COENSGEN, AND A. E. SHERMAN, *Lawrence Radiation Laboratory, Livermore.*—It has been predicted that the principal interaction that should be observed during the collision of two plasma streams would be the production of a shock front at the interface and the very rapid transfer of the plasma translational energy into the energy of the plasma oscillations.[1–3] Two of the 800 ev plasma generators developed by this group[4] were mounted at opposite ends of a 20 ft long vacuum system, 18 in. in diam. The vacuum system is immersed in a uniform longitudinal magnetic field which can be varied over the range of 0–800 gauss. Magnetic and extraction probes were utilized to observe the interactions for various values of magnetic field. It appears that although some effects were observed which were not simply additive, strong shocks were not observed. Perhaps this absence of strong shock formation is due to the appreciable velocity dispersion of the ions.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] F. D. Kahn, J. Fluid Mech. 2, 601 (1957).
[2] E. N. Parker, Astrophys. J. 129, 217 (1959).
[3] O. Buneman, Phys. Rev. 115, 503 (1959).
[4] W. F. Cummins, F. H. Coensgen, A. E. Sherman, and W. E. Nexsen, Bull. Am. Phys. Soc. Ser. II, 5, 318 (1960), this issue.

**E12. Plasma Alfvén Waves: Velocity and Attenuation.*** ALAN W. DE SILVA, FORREST I. BOLEY,† AND JOHN M. WILCOX, *Lawrence Radiation Laboratory, Berkeley.*—Torsional Alfvén waves have been propagated through a cylindrical plasma. The wave, induced at one end by a voltage applied between coaxial conductors, is detected at the far end as a voltage appearing on two similar conductors. Hydrogen gas at 100 $\mu$ is used with a magnetic field of 10 kilogauss. The plasma is contained in a copper cylinder 34 in. long and $5\frac{3}{4}$ in. in diam. The theoretical velocity is $v_A = B/(4\pi\rho)^{\frac{1}{2}}$. The predicted linear dependence on magnetic field is verified experimentally, and from the measured velocity a density $\rho$ can be determined. Neutral atoms present may contribute to this density if the frequency of collisions between ions and neutrals is large compared with the wave frequency. Newcomb has shown that the attenuation caused by finite conductivity leads to a decay length $(1/e)$ of $2\mu_0\sigma v_a/(k_z^2+k^2)$, and a lower limit for the decay length caused by collisions with neutrals is $2v_a/\nu_{in}$, where $\nu_{in}$ is the ion-neutral collision rate. This linear dependence of attenuation on magnetic field has been verified experimentally.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Summer visitor from Wesleyan University, Middletown, Connecticut.

**E13. Plasma Alfvén Waves: Power Transfer and Impedance.*** JOHN M. WILCOX, FORREST I. BOLEY, AND ALAN W. DE SILVA, *Lawrence Radiation Laboratory, Berkeley.*—Probe measurements of the magnetic field associated with the Alfvén wave discussed in the preceding abstract have verified the theoretical prediction that the principal component is $b_\theta$. The radial and axial components $b_r$ and $b_z$ are an order of magnitude smaller. The peak magnetic field associated with the wave is about 100 gauss, which is 1% of the constant applied field, so that a small-amplitude theoretical treatment is valid. The energy content of the wave consists of $b_\theta^2/8\pi$ energy (measured experimentally with the magnetic probe), plus an equal amount of energy associated with kinetic energy of the transverse plasma velocity. The energy in the wave was measured as $(43\pm10)\%$ of the input energy from the external oscillating circuit. The remaining energy may be lost at the insulators or at a sheath. The impedance of the coaxial hydromagnetic waveguide may be calculated from $Z_0/\sqrt{K}$, where the vacuum impedance $Z_0$ is a function of the two radii and $K$ is the plasma dielectric constant. The measured and calculated impedances agree very well, but the measured impedance is not as strongly dependent on magnetic field as the linear relationship predicted theoretically.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**E14. Propagation of Ion Cyclotron Waves.*** THOMAS H. STIX AND RICHARD W. PALLADINO, *Project Matterhorn, Princeton University.*—A single turn magnetic probe has been used to investigate the rf magnetic field distribution in the plasma during ion cyclotron resonance heating in the B-65 Stellarator. Wave propagation is observed only when the rf generator frequency is below the ion cyclotron frequency, which is in accordance with theory.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] T. H. Stix, Phys. Rev. 106, 1146 (1957).

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## FRIDAY MORNING AT 9:00

## King Hall

## (A. H. SNELL presiding)

**F1. Plasma Jet Electrical Characteristics.** H. K. GATES, JR.,* AND J. K. THOMAS,* *U. S. Naval Postgraduate School.*—The plasma jet has recently become the subject of considerable interest, particularly as a research tool for the production of extremely high temperatures, and as a source of high temperature, high Mach number flows for laboratory investigations. The authors have been primarily concerned with the development of such a device and its associated hardware, for use at electrical energy levels in the order of three megawatts. Basic emphasis in this investigation was placed upon certain of the electrical parameters, in particular voltage and current variation with changing electrode separation. As a result of this investigation, a working method for adjusting the power level of the plasma jet was evolved. As a by-product of the design calculations and investigations made, considerable information has been obtained on the flow parameters of the swirling fluid media used to contain the arc, and on the fluid and electrical parameters of the internally cooled coils used to obtain the magnetic field necessary for magnetic confinement attempts.

* Lieutenant, U. S. Navy.

**F2. Plasma Acceleration Studies.*** W. H. BOSTICK, J. DIMARCO, SAMUEL KOSLOV, J. NANKIVELL, H. DICKINSON,† G. SCHMIDT, AND J. SINNIS, *Stevens Institute of Technology.*—Work is continuing on the acceleration of plasma by means of rail guns. In addition to the parallel rail type, a coaxial gun has been placed into operation. Sources of plasma include direct ionization of gas and "button" guns. A type of plasma projector called the "funnel" is discussed, utilizing compressive heating and acceleration in a divergent magnetic field. A series of measurements of plasmoids fired into and out of a diverging magnetic field are reported on. Some observations of possible flute-type instabilities will be reported on. Considerable emphasis has been placed on diagnostic methods for determining

composition and velocity of the high velocity plasmas. Electronically and magnetically biased probes will be described. Excellent correlation has been obtained between microwave doppler shift velocity measurements and time-of-flight probe measurements.

* Work supported by Sherwood Branch, U. S. Atomic Energy Commission, Flight Propulsion Division, General Electric Company and Air Force Cambridge Research Center.
† U. S. Military Academy, West Point, New York.

**F3. Experiments on Supersonic Plasma Flow along Magnetic Fields. II.*** DAVID M. WETSTONE, *Institute of Mathematical Sciences, New York University.*—Experimental results are presented, via time-integrated photographs, of collimated Cu plasmoid flow parallel to magnetic fields up to 3 weber/m², with transverse confinement into and out of magnetic mirrors. Mirror geometries expanded and compressed the plasma flow, which tended to follow the field lines. Photomultiplier studies determined center-of-mass and expansion velocities which, in later experiments, reached 5.5 and 1.9 cm/μsec, respectively, adequately demonstrating supersonic flow. The latter figure, interpreted to represent an upper bound to ion temperature, corresponds to 120 ev for Cu. This ion energy is considerably higher than those normally encountered in spark channels and is a substantial fraction (0.12) of the axial energy. A mechanism is suggested for achieving such thermal energies through the interaction of a strong shock wave with the initial discharge channel. This work is a logical extension of that reported by Finkelstein et al.,[1] and continues the project first described by Wetstone et al.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] D. Finkelstein, G. A. Sawyer, and T. F. Stratton, Phys. Fluids **1**, 188 (1958).
[2] D. M. Wetstone, D. Finkelstein, M. P. Ehrlich, and I. Livingston, Bull. Am. Phys. Soc. Ser. II, **4**, 41 (1959).

**F4. A Two-Stage Plasma Accelerator.*** H. P. FURTH AND F. O. HALLIDAY, *Lawrence Radiation Laboratory, Livermore.*—The principle of storing energy "capacitatively" in a moving plasma has been discussed in a previous publication.[1] This principle is being put to use in the design of a two-stage plasma accelerator of the rail type. A steady magnetic field will be employed, orthogonal to the direction of motion and to the direction of the electric field between the rails. The magnetic field is designed to drop off sharply in space to a lower value, at a specific point along the rails. A body of plasma is accelerated to equilibrium velocity $v=(E/H)c$ in the usual way, by means of a transient current between the rails. As the plasma front passes through the discontinuity in magnetic field, the motional emf in the front region drops. There results a transient current accelerating the front toward a higher equilibrium velocity, and decelerating the bulk of the plasma. The rate of energy transfer to the front depends on the Alfvén velocity in the bulk of the plasma, and can be made large if one uses a strong steady magnetic field.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] O. Anderson, W. R. Baker, A. Bratenahl, H. P. Furth, and W. B. Kunkel, J. Appl. Phys. **30**, 188 (1959).

**F5. Hydromagnetic Plasma Gun.*** JOHN MARSHALL, *Los Alamos Scientific Laboratory.*—A coaxial plasma gun has been developed capable of transferring 1200 joules of kinetic energy to about 100 μg of hydrogen plasma from a 5000 joule capacitor bank with an energy input at the gun terminals of 2700 joules. The plasma is capable of piercing its way into approximately a 10 000 gauss magnetic field. Gas is admitted impulsively to the initially evacuated gun by means of a mechanical valve. Effectively all of the gas admitted is accelerated. Spectroscopic observations indicate that the plasma is free of electrode materials under certain conditions. Electric and magnetic analysis of a collimated sample of the plasma indicate a proton velocity spread of less than a factor 2.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**F6. Study of an 800 ev Plasma Generator.*** W. F. CUMMINS, F. H. COENSGEN, A. E. SHERMAN, AND W. E. NEXSEN, *Lawrence Radiation Laboratory, Livermore.*—A parametric study has been made of the plasma generator described earlier.[1,2] In this device the plasma is generated and accelerated by a pulsed high current arc within a cylindrical stack of interleaved metal and ceramic annuli. Formerly, all of the metal annuli were made of deuterated titanium. By systematically substituting tantalum for deuterated titanium, the electrode which is initially the anode, was found to be the principal source of energetic deuterium plasma. For best operation this electrode forms the orifice of the stack. Observations were made for variations in the stack length, stack division, polarity of discharge, stored energy in the arc supply, and other circuit parameters. The average energy and amount of energetic plasma ejected by the source was strongly affected by the degree of stack division and the discharge polarity. The amount of plasma varied more or less linearly with stored energy, while the average energy was relatively insensitive to this parameter.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] F. Coensgen, W. Cummins, and A. Sherman, Bull. Am. Phys. Soc. Ser. II, **3**, 416 (1958).
[2] F. Coensgen, W. Cummins, and A. Sherman, Phys. Fluids **2**, 350 (1959).

**F7. State of Deuterium Atoms in Energetic Plasma Sources.** S. S. SIDHU, *Argonne National Laboratory.*—Studies of deuterated metals used for plasma sources with neutrons and x-ray diffraction show that deuterium reacts with metal atoms and forms metal deuterides that have entirely different crystalline structures than those of metals. The gas atoms are not adsorbed at the surface of the metal, nor do they go into the interstitial sites in the metal as is commonly inferred, the interstitial solid solution of deuterium in these metals being extremely small, if any. In a deuteride structure, which may be formed at nonstoichiometeric ratio of metal and gas atoms, the atoms take definite positions with respect to their neighbors and the bonds between metal-gas atoms are shorter than between metal-metal atoms. The deuterium atoms thus bonded in the deuteride structure leave the lattice only at the dissociation temperature and pressure of the deuteride. An assembly of deuterated discs, as in a plasma source, loses deuterium from the parts that are heated to the dissociation temperature, leaving the unheated parts in the original state. The depleted parts convert to metallic state.

**F8. A High Current Duoplasmatron Ion Source.** G. G. KELLEY, N. H. LAZAR, AND O. B. MORGAN, *Oak Ridge National Laboratory.*—The results of experiments with the duoplasmatron of von Ardenne[1] will be described. Ion currents of up to 150 ma at 75 kv have been obtained using a copper anode with shrink-fitted tungsten insert having an 0.046-in. aperture. The current has been limited to this value by the power supply used.

Gas efficiency at 150 ma output was 81%. The anode arc current was 8 amp. Considerably greater output per ampere of anode arc current has been obtained under other conditions of source geometry. Sixty ma have been extracted with 1 amp of arc current.

[1] M. von Ardenne, *Tabellen der Elektronenphysik, Ionenphysik, and Übermikroskopie* (VEB Deutscher Verlage der Wissenschaften, Berlin, 1956).

**F9. A Plasma Parametric Amplifier.** G. S. KINO AND B. LUDOVICI, *Microwave Laboratory, Stanford University.*—A new type of parametric traveling-wave amplifier is described

which makes use of the nonlinear properties of a gas-discharge plasma through which propagate electromagnetic waves. A theory which predicts the gain of this amplifier is given, the theory being based on taking second-order terms in the equations of motion into account. Early experimental results with such a device are given; it is shown that the parametric effects are present although the pumping powers required to obtain gain are an order of magnitude greater than is predicted by the theory.

**F10. An Electromagnetically Driven Shutter and Valve for the Microsecond Range of Open Times.*** H. FULBRIGHT,† P. LAMPERTI, AND C. OXLEY, *General Atomic.*‡—A mechanical shutter which can be opened and shut electromagnetically in times as short as 1 μsec has been developed. The moving element is a thin strip of aluminum foil which moves edgewise so that a slit through its center passes between two fixed slits. A fast valve based upon the same principle is also described. In this case the fixed slits are surrounded by rubber O rings which press against the two sides of the moving element. Applications to plasma work in addition to fast gas valving into discharge tubes are gating of electromagnetic radiation to slow response black receivers and gating of particles for time of flight analysis.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Energy Research Foundation.
† University of Rochester, Department of Physics and Astronomy, Rochester, New York.
‡ John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

**F11. A Fast High-Current High-Voltage Vacuum Switch.*** A. H. WILLIAMS AND J. W. MATHER, *Los Alamos Scientific Laboratory.*—This paper discusses the important aspects of a graded vacuum spark gap having the following characteristics: dc voltage range (100 v–20 kv), inverse pulse voltage holdoff (~38 kv), current (~300 ka), inductance (~5 mμh), resistance, timing (~$10^{-8}$ sec), repetition rate, crowbar feasibility, and lifetime (>5000 discharges). Ten such vacuum switches are currently employed in close parallel connection to a low inductance load. Pyrex glass insulators are used as the principal dielectric between the brass electrodes. Normal deposition of the evaporated electrode material on the insulators is eliminated by a conditioning process. The mechanism whereby the metallic cloud is selectively deposited on the insulator is discussed from the point of view of establishing a large number of nucleation centers by a crazing[1] of the glass surface.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Crazing of glass is a result of thermal expansion and contraction due to intense surface heating.

**F12. The Megatron.** K. C. ROGERS, G. BRUCKER, D. FINKELSTEIN, L. FERRARI, I. MANSFIELD, AND D. CAULFIELD, *Stevens Institute of Technology.*—The Megatron, a 1000-amp, 150-Mev space charge neutralized betatron is briefly described. A beam intensity limitation for high beam current betatrons is stated and applied to the machine. The goal of 1000 amp is well within the limit set by this expression. Preliminary results obtained with the machine operating at low energy are presented.

**F13. Space Charge Effects in an Ion Energy Analyzer.*** H. W. BANDEL,† *Lawrence Radiation Laboratory, Livermore.*—An ion energy analyzer has been developed using 45° magnetic field deflection, followed by 90° electrostatic field deflection. It was found to suffer from ion space charge effects in the magnetic unit. These effects could be alleviated, but not eliminated, by placing screens closely adjacent to the proper ion trajectory. They were finally overcome by utilizing the high sensitivity of an electron multiplier detector to permit working with smaller ion flux into the analyzer. The electron multiplier is biased so that all ions reach it with the same energy, thus eliminating the need for calibration as a function of incident ion energy. The method of testing will be described and typical results shown.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Sylvania Electric Products Inc., Microwave Physics Laboratory, Mountain View, California.

**F15. Ion Beam Space Potential Measurement with an Electron Beam.*** T. O. PASSELL,† *Lawrence Radiation Laboratory, Livermore.*—An electron beam of 30 to 100 ev kinetic energy has been used to measure space potential in a pulsed, 3 to 8 kev, $H^+$ beam. The ions were produced in a titanium hydride source designed for high energy injection into a mirror machine. Ions were directed transverse to a >1000 gauss uniform magnetic field. Measurements were made in the region of the 180° focal plane of the ions. The electrons passed parallel to a grounded metal plate about 1 mm from its surface, the latter placed near, but outside the ion beam to attract the space charge electric lines of force. The plate was oriented to guarantee that, close to its surface, $E \cdot B = 0$. Electron beam deflections (they were in the direction $E \times B$, parallel to the grounded metal plate) were recorded photographically from the beam trace on a phosphor-coated metal plate. The electric field due to space charge varied with time during the pulse (pulses were 400 μsec long) and with background gas pressure as one would expect (decreases with both time and gas pressure increases). An upper limit of 40% neutralization was the measured value averaged during the first 100 μsec at base pressure ($3 \times 10^{-7}$ mm Hg) under one particular set of conditions.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Stanford Research Institute, Menlo Park, California.

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FRIDAY AFTERNOON AT 2:00

King Hall

(LYMAN SPITZER, JR., presiding)

## *Invited Papers*

**G1. Cooperative Phenomena in Plasma Diffusion across a Magnetic Field.** LUDWIG BIERMANN AND D. PFIRSCH, *Max-Planck Institute.* (30 min.)
**G2. Theory of Transport Process.** E. W. MONTROLL, *University of Maryland.* (30 min.)
**G3. Nonlinear Effects in Plasmas.** P. A. STURROCK, *Stanford University.* (30 min.)

FRIDAY AFTERNOON AT 3:45

King Hall

***Business Meeting***

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FRIDAY EVENING AT 6:30

***Cocktail Hour***

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FRIDAY EVENING AT 7:30

Hermann Hall

(M. B. GOTTLIEB presiding)

***Banquet of the Division of Plasma Physics***

Speaker: E. TELLER, A Long View of Sherwood

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SATURDAY MORNING AT 9:00

Spanagel Hall

(E. GERJUOY presiding)

**H1. A Method of Solving the Boltzmann Equation of Gases in the Presence of Medium-Range Forces and Its Applications to Plasma Oscillations.*** TOYOKI KOGA, *Engineering Center, University of Southern California.*—A method of approach of treating the Boltzmann equation of gases in the presence of long- or medium-range forces is proposed. Force $\mathbf{F}$ is divided into two parts, $\mathbf{F}^0$ and $\mathbf{F}'$, where $\mathbf{F}^0$ is simple and $\mathbf{F}'$ is rather complicated. Assuming that the number density of particles of velocity $\mathbf{c}^0$ and of position $\mathbf{r}^0$ in the presence of $\mathbf{F}^0$ is known and is given by $f(\mathbf{c}^0,\mathbf{r}^0,t)$, the number density of particles of velocity $\mathbf{c}$ and of position $\mathbf{r}$ in the presence of force $\mathbf{F}^0+\mathbf{F}'$ is shown to be given by $f(\mathbf{c}-\mathbf{c}',\mathbf{r}-\mathbf{r}',t)$. Here $\mathbf{c}'$ and $\mathbf{r}'$ are the effects of $\mathbf{F}'$ on the variables, velocity and position, which specify a trajectory line. As an example of the theory, Dawson's theory of plane oscillations of electrons in a cold plasma is extended to be applied to plane oscillations in a hot plasma.

* This work was supported by the Office of Scientific Research, U. S. Air Force.

**H2. Large Amplitude Plasma Waves. I. Scalar Pressure.*** ALFREDO BAÑOS, JR., AND RUSSELL VERNON, *University of California, Los Angeles.*—We consider an infinite expanse of low density, fully ionized plasma in a constant and uniform field of magnetic induction. In the absence of collisions the ion and electron motions take place in planes perpendicular to the magnetic field. We transform to a "shock" frame of reference moving at constant speed at right angles to the magnetic field, and then we search for the class of nontrivial, time-independent, one-dimensional, self-consistent solutions of the Maxwellian set and of the equations of motion of the charged particles. Assuming charge neutrality and isotropic pressure, the system of equations can be solved numerically by a quadrature. We find symmetric pulses and nonlinear periodic waves with characteristic lengths of the order of the mean gyromagnetic radius. The whole problem can be specified in terms of the Alfvén Mach number $\alpha$, which gives a measure of the speed of propagation, and of the ratio $\beta$ of the total plasma pressure to the magnetic pressure. We find that, for a given $\beta$, stationary solutions exist only for a limited range in $\alpha$. In particular, we find that for certain ranges of $\alpha$ and $\beta$ no periodic solutions exist at all.

* Supported by the U. S. Atomic Energy Commission through the Lawrence Radiation Laboratory.

**H3. Large Amplitude Plasma Waves. II. Nonisotropic Pressure Tensor.*** RUSSELL VERNON, *University of California, Los Angeles.*—The study of the propagation of compression waves across a magnetic field in a fully ionized plasma (see preceding abstract) has been extended to include the effects of the nonisotropic components of the pressure tensor. The particle motions are essentially two-dimensional, so that only two nonisotropic components appear, in addition to the perpendicular "hydrostatic pressure." The nonlinear system of equations involving the magnetic field, two velocity components, and the three pressure components has been solved numerically. The results agree qualitatively with the results obtained analytically in the absence of the nonisotropic terms, except that the solutions are complicated by the existence of "stress waves" in which the two nonisotropic components are the major participants. In the limit as the temperature approaches zero, the frequency of these stress oscillations approaches twice the cyclotron frequency. Owing to the multiplicity of elementary solutions, complicated aperiodic waves can appear, as well as pulses and periodic waves like the isotropic solutions. The more regular solutions not only have

similar shapes, but also exhibit amplitudes, frequencies, and domains of existence close to those for the isotropic case.

* Supported by the U. S. Atomic Energy Commission through the Lawrence Radiation Laboratory.

**H4. Plasma Electron Wave Surfaces.*** W. P. ALLIS AND R. J. PAPA, *Massachusetts Institute of Technology.*—A plane electromagnetic wave splits into two with different polarizations when propagating in a cold plasma in a magnetic field. The resonances and cutoffs for these waves were discussed at the Gatlinburg meeting (April 27 and 28, 1959) and all types of wave-normal surfaces were shown. In a hot plasma a plane wave splits into three of differing polarizations and the third wave, whose velocity is of the order of a sound wave, will be termed "plasma wave." The wave surfaces of the plasma waves will be shown for wave frequencies well above ion cyclotron frequency. Their polarization, which is longitudinal only in special cases, and their relation to plasma oscillations, will be discussed.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research); and in part by the U. S. Atomic Energy Commission and the National Science Foundation.

**H5. Hydrodynamic Interpretation of Plasma Electron and Ion Oscillations.*** R. L. MOORE, *Richard L. Moore Consultants.* Collective flow of the plasma through a throat formed by a pinch effect (or local constriction) with transverse oscillations of the plasma surface is proposed as explanation for the glow discharge experiments of Mahaffey.[1] The meniscus, or glow, may be due to intense high-frequency radio waves which ionize the residual gas near the throat. Qualitative agreement is found between the frequency of the oscillations and that predicted.[2] The growth of the throat, and the presence of multiple throats will be shown to be a possible reason for the variation of discharge types. Further application of the theory to interpretation of the experiments of B. Lehnert, and T. K. Allen[3] is indicated. Evidence for this theory being a partial explanation of the diffusion of energy from an arc across a magnetic field will be presented.

* Work supported by Norair, a division of Northrop Corporation.
[1] D. W. Mahaffey, J. Electronics and Control **5**, 193 (1959).
[2] R. L. Moore, Bull. Am. Phys. Soc. Ser. II, **4**, 247 (1959).
[3] T. K. Allen, G. A. Paulika, and R. V. Pyle, 12th Annual Gaseous Electronics Conference (1959), paper G7.

**H6. On the Green's Function for Two Dimensional Magnetohydrodynamic Waves.** HAROLD WEITZNER, *Institute of Mathematical Sciences, New York University.*—The Green's Function for the linearized Lundquist equations for a two dimensional system, interpreted in the sense of a distribution, is evaluated. The magnetic field and matter density are given explicitly, and the flow velocity in terms of integrals of these. As has been derived elsewhere,[1] the ray sruface, in the nondegenerate case of unequal sound speed and Alfvén speed, consists of two closed cusped curves within a convex curve, the latter defining the range of influence for the equation. It is shown that the matter density and magnetic field vanish within the cusped regions. The nature of the singularities at the ray surface is given, as well as the qualitative behavior of the function.

[1] See the paper of H. Grad in *The Magnetohydrodynamics of Conducting Fluids* (Stanford University Press, 1959) or Bazer and Fleishman, Phys Fluids **2**, 366 (1959).

**H7. Coherent and Incoherent Radiation from a Plasma.** E. G. HARRIS AND A. SIMON, *Oak Ridge National Laboratory.*—The Vlasov equations have been derived previously by starting from the Liouville equation and treating both plasma particles and electromagnetic field statistically.[1] A by-product of this derivation was an equation for $f^{\lambda}(q_{\lambda},p_{\lambda})$, the probability density in the phase space of one of the radiation field oscillators. These functions may be used to define an entropy for the electromagnetic field. If the phases and amplitudes of all electromagnetic waves are precisely defined (coherent radiation), the field entropy is negatively infinite. Any incoherence increases the entropy. It may be shown from the Vlasov equations that the field entropy is a constant of the motion. This is analogous to Newcomb's proof that the particle entropy is constant.[2] It follows that incoherent radiation cannot be calculated from the Vlasov equations. This calculation suggests that in a higher approximation $f^{\lambda}$ should obey an equation of the Fokker-Planck type which would predict incoherent radiation from a plasma.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.
[1] E. G. Harris, Naval Research Laboratory Report 4944 (May 17, 1957).
[2] I. B. Bernstein, Phys. Rev. **109**, 10 (1958).

**H8. Kinetic Equations for Plasma and Radiation.** A. SIMON AND E. G. HARRIS, *Oak Ridge National Laboratory.*—Rosenbluth and Rostoker[1] have proposed a new method of expansion in powers of the coupling constant $e$ which enables one to solve the coupled chain of equations resulting from partially integrating the Liouville equation in $6N$ dimensions. The resulting lowest order equation is the Vlasov equation, the next is the Fokker-Planck, etc. We have generalized the method to include both particles and radiation on an equal footing. The expansion parameters are now $e$ and the reciprocal volume. In lowest order the resulting equations are the Vlasov equations for the particles and a "Vlasov"-like equation for the field oscillators.[2] In next order, one obtains two coupled equations relating $g(1,2)$, the two particle correlation function, and $g(1,\lambda)$, the particle-oscillator correlation function. The usual Fokker-Planck terms for particles are contained in $g(1,2)$ while $g(1,\lambda)$ represents the essential part of a *Fokker-Planck equation for radiation.* This should be the most general way to calculate incoherent radiation from a plasma.

* Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.
[1] M. Rosenbluth and N. Rostoker, General Atomic Report GAMD-663 (January, 1959).
[2] E. G. Harris and A. Simon, Bull. Am. Phys. Soc. Ser. II, **5**, 321 (1960), this issue.

**H9. Oscillations of a Nonuniform Plasma.** ERICH S. WEIBEL.—The confinement of a plasma by a radiofrequency field is characterized by the effective confining potential $\psi=\frac{1}{2}m\omega_0 x^2$. The plasma oscillations of the electrons are determined from the self-consistent Boltzmann transport equation. This equation is linearized about the equilibrium distribution $f_0=\exp(-1/kT)(\psi+\frac{1}{2}mv^2)$. By expanding the electric field in Hermite polynomials it is possible to reduce the resulting integro-differential equation to an infinite system of linear equations for the coefficients of the expansion. The resonant frequencies are the roots of the determinant. For low electron density the resonant frequencies approach the integral multiples of $\omega_0$ and increase with increasing density. The lowest two resonant frequencies are calculated approximately as a function of the density as the roots of small subdeterminants.

**H10. Cyclotron Harmonic Radiation from Plasmas.** J. L. HIRSHFIELD AND D. E. BALDWIN, *Massachusetts Institute of Technology.*—Schwinger's formula[1] for the radiation from high-energy electrons orbiting in a magnetic field has been used for calculating the cyclotron radiation from a plasma in thermal equilibrium. In our model a group of electrons within a given velocity interval are supposed to contribute a collision-broadened line around each harmonic. Relativistic mass change and the Doppler effect taken into account for each elementary line, and integration over all velocity intervals gives the total line profiles emitted by a uniform plasma slab. The higher harmonics merge into a continuum, but individual maxima all fall below a freqiency $\omega_M=(mc^2/kT)\omega_b$.

This calculation is correct only when the value of the total radiated intensity falls considerably below half that of the corresponding black-body emission, but intensities up to the black-body may be correctly inferred if the plasma is tenuous. The calculation is valid only for electron temperatures lower than approximately 100 kev. Our results are compared with those of Trubnikov[2] and Beard.[3]

[1] J. Schwinger, Phys. Rev. **75**, 1912 (1949).
[2] B. A. Trubnikov, Soviet Phys. "Doklady" **3**, 136 (1958).
[3] D. B. Beard, Phys. Fluids **2**, 379 (1959).

**H11. Effects of Collisions on the Cyclotron Radiation from Relativistic Particles.*** LUDWIG OSTER, *Laboratory of Marine Physics, Yale University* (introduced by D. Mintzer).—The effects of collisions on the cyclotron radiation from relativistic electrons are considered, making use of a very simple model for the collisions processes. The basic assumption is that the particle radiates during certain time intervals $\Delta t$, their probability being distributed according to the statistical law $\exp(-\Delta t/T_0)$ with $T_0$ as mean collision time. Numerical calculations have been carried out to determine the spectral and angular behavior for various values of the magnetic field strength, the mean collision time and the particle's energy. Of particular interest are "line shape" and relative intensity of the higher harmonics and their angular intensity distribution.

* Supported by the Office of Naval Research.

**H12. Electromagnetic Scattering from a Plasma Column.** R. W. GOULD, *California Institute of Technology.*—The effect of electron thermal velocities upon scattering of electromagnetic waves from a cylindrical plasma column has been investigated by including a scalar pressure term in the momentum equation. In addition to the usual resonance[1] at $\omega^2 \approx \omega_p^2/2$, it is shown that the scattering cross section also exhibits a series of resonances at frequencies $\omega_n$ given by $\omega_n^2 = \omega_p^2 + k_n^2 w^2$. $k_n$ is an eigenvalue of the radial propagation equation for plasma oscillations and $w$ is the electron thermal velocity. Each resonance corresponds to a normal mode of oscillation in which different parts of the plasma cylinder oscillate with different phases. Theories[1] of scattering from a cold plasma yield only a single resonance in the scattering cross section at $\omega^2 = \omega_p^2/2$ although infinitely many normal modes of oscillation exist at $\omega^2 = \omega_p^2$ which do not couple to external fields. The electron thermal velocities apparently cause a coupling to the external field and a splitting in the resonant frequencies. This result may explain the multiple resonances in the experiments of Romell, Dattner, and Boley.[2] A quantitative discussion of this point will be given.

[1] N. Herlofson, Ark. Fysik **3**, 247 (1951).
[2] F. I. Boley, Nature **182**, 790 (1958).

**H13. A Weak Dispersion Anomaly for Propagating Electromagnetic Waves in Distributed Plasmas.** J. W. CHRISTIE, *Lockheed Aircraft Corporation, Missiles and Space Division* (introduced by R. G. Gunton).—Normal dispersion is defined as the case of an infinite plane electromagnetic wave propagating through a uniform plasma. One finds for finite waves in a bounded nonhomogeneous plasma that under certain conditions the space charge fields due to density gradients produce restoring forces which increase the dipole polarization term anomalously. The over-all effect is that the electron density defined by propagation cutoff is now decreased by a factor as large as two when compared with the normal case. The particular value of decrease depends on the field and plasma distributions involved. Theoretical results for several simple distributions will be presented.

**H14. Conditions for Maximum Power Transfer to a Plasma.** R. A. GERWIN, B. G. SPRINGER, AND J. E. DRUMMOND, *Boeing Scientific Research Laboratories.*—Using the linearized Boltzmann equation, together with Maxwell's equations, it has been shown[1] that a generalized conductivity relation is valid for electron plasmas. From this relation, an expression for the total, time-average power transfer between the plasma and an externally applied field has been derived. An inhomogeneous integral equation for the electric field has also been derived. The condition for maximizing the power transfer expression will be stated, and will then be used in connection with the integral equation for the electric field to relate the maximizing condition to the perturbation conditions on the plasma boundary. An example will then be discussed.

[1] J. E. Drummond, R. A. Gerwin, and B. G. Springer, "The concept of conductivity," presented at the 1959 International Plasma Physics Institute, Seattle, Washington (August 31–September 5, 1959).

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## SATURDAY MORNING AT 9:00

## King Hall

## (J. M. B. KELLOGG presiding)

**J1. Magnetic Field Distribution and Optical Measurements in Perhapsatron S-5.*** D. C. HAGERMAN AND J. P. MIZE, *Los Alamos Scientific Laboratory.*—Perhapsatron S-5 is a toroidal pinch machine similar to those previously studied at Los Alamos but a factor of two larger in all linear dimensions than its predecessor, Perhapsatron S-4. Its major diam is 125 cm, minor diam 28 cm; 60 kv may be applied around the torus with a peak gas current of 300 ka and a full period of 40 $\mu$sec. The magnetic field distribution in the discharge has been measured. From this the current distributions have been derived and the total energy contained in the magnetic field calculated. The difference in energy removed from the condenser banks and stored in the magnetic field is ~100 ev/gas particle. The sheath has a half-width of 1.5 cm. These measurements extend in time to ~10 $\mu$sec, after which results are unreliable due to irreproducibility of probe signals. The width of He II 4686 A has been measured as a function of time. It has not yet been possible to determine whether this line broadening is due to turbulence or to an ion temperature.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**J2. Diagnostic Measurements on Perhapsatron S-5.*** J. MIZE, D. HAGERMAN, AND D. LIER, *Los Alamos Scientific Laboratory.*—The operational characteristics of the toroidal stabilized pinch machine, Perhapsatron S-5, have been examined to determine energy loss mechanisms, temperature of the plasma, and plasma composition. The electromagnetic radiation regions investigated include: x-ray region 0.5 to 2000 kev, ultraviolet region 50 to 1100 A and the visible light spectrum 3500 to 8000 A. X-rays produced by runaway electrons of maximum energy ~170 kev have been found to be emitted during approximately the first 15 $\mu$sec of the discharge. A hard x-ray component of energy ~1.5 Mev, duration ~2 $\mu$sec, is observed at the time of the first current maximum. The

onset time of ultraviolet radiation, comprising the major energy loss component from the discharge, has been found to be dependent on the initial deuterium gas purity. Thus, through improvement in the base pressure it is possible to delay the onset of this radiation loss past the first current maximum. Time of flutter of magnetic field probe signals indicating instability of the discharge has been measured and compared with onset time of ultraviolet radiation, x-ray production, and neutron emission. Conclusions drawn from the data in an attempt to arrive at a consistent description of the operation of the machine will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**J3. Experimental Study of the Super Fast Pinch.** L. O. HEFLINGER AND S. L. LEONARD, *Space Technology Laboratories, Inc.*—The basic idea of the super fast pinch is the "heating" of a plasma to thermonuclear "temperatures" by means of a nonadiabatic pinch in which the gas ions are accelerated to thermonuclear velocities by the first contraction of the pinch. An apparatus has been constructed to test the basic predictions of the theory. The characteristics of the experimental assembly are: $C \sim 3000$ $\mu$f, $I \sim 70\,000$ amp, $V \sim 350$ kv, $f \sim 20$ Mc. This capacitor is discharged into a highly ionized plasma injected by an electromagnetic shock tube. Diagnostics include image converter streak photographs and a measurement of $\int E \cdot dl$ along the inner wall of the pinch tube. These diagnostics indicate a converging cylindrical shock wave of average velocity $3 \times 10^7$ cm/sec and maximum velocity at least three times as great. It also appears that magnetic flux associated with a contraction of the current column is trapped within the pinch tube for several cycles of the discharge current.

**J4. Instability of a Hydromagnetically Stable Pinch Configuration.*** D. H. BIRDSALL, S. A. COLGATE, AND H. P. FURTH, *Lawrence Radiation Laboratory, Livermore.*—In a hard-core pinch tube[1] an "inverse stabilized pinch" can be produced, with $H_\theta$ on the inside of the tubular region of current flow, and $H_z$ on the outside. The observation of small-scale instabilities in this hydromagnetically stable configuration has been reported previously.[1] Because the configuration is usually created by pinching away from the center rod, an outward convexity of the longitudinal field lines is observed near the electrodes, and this has given rise to some question about local hydromagnetic stability. The experiment has now been repeated with an initial longitudinal field sufficiently concave so as to remain concave throughout the cycle. The inverse stabilized pinch configuration has also been created by pinching an initial $H_\theta$ inward with a fast-rising $H_z$. In each case, the configuration is still found unstable. These experiments seem to demonstrate that at typical pinch currents of a few hundred thousand amperes and lines densities of $10^{18}$–$10^{19}$ cm$^{-1}$, nonhydromagnetic instabilities can play a prominent role.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] D. H. Birdsall, S. A. Colgate, and H. P. Furth, "The hard-core pinch. I", *Proceedings Fourth International Conference on Ionization Phenomena in Gasses, Uppsala, 1959* (North-Holland Publishing Company, Amsterdam, 1959).

**J5. Small Levitron.*** R. SPOERLEIN, S. A. COLGATE, H. P. FURTH, L. SANDY, AND O. TWITE, *Lawrence Radiation Laboratory, Livermore.*—A small version (3½-in. minor diam, 60 000 amp) of the toroidal form of the hard-core pinch has been operated in order to confirm theories of levitation of the hard-core ring, and entrapment of generalized field distributions, as well as for reproduction in toroidal geometry of the stability results obtained with the linear hard-core pinch. Vacuum field measurements confirm the levitation theory for both a single large current pulse and for cw 60 cycle current. When an ionized plasma is formed around the levitated core, magnetic field measurements at the wall demonstrate that $H_\theta$ field can be entrapped and compressed against the core by means of a fast-rising $H_z$ field. Alternatively, one can produce the standard configuration where an initial $H_z$ field is entrapped by means of a fast-rising $H_\theta$. Detailed probe measurements made with a mechanically supported core confirm the greater stability of the hard-core distribution with trapped $H_\theta$ as compared with the so-called stabilized pinch distribution with trapped $H_z$. Measurements of plasma and energy containment times are not yet affected by stability, because of the low plasma purity and weak magnetic fields employed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**J6. Enhanced Diffusion Due to Magnetohydrodynamic Turbulence.** S. A. COLGATE, *Lawrence Radiation Laboratory, Livermore.*—Turbulence in combined plasmas and magnetic fields, due to instabilities, has been observed for some time, but even a qualitative description of the phenomenon has been lacking. From the observed (with magnetic probes) large fractional energy density in the distortion of the lines of force, and the small correlation distance, one suspects the transfer of substantial energy to high harmonics of Alfvén waves by nonlinear processes. Shock wave type phenomena are expected to result. In infinite geometry the "weak" collisionless shock wave structure is dominated by a charge separation electric field. In finite geometry (wavelength comparable to the ion Larmor radius) the charge separation electric field is neutralized by current flow along the lines of force in times of the order $1/\omega_p$, resulting in a shock thickness greater than the ion Larmor radius. The only residual electric fields are those due to the anisotropy of the ion energy distribution which causes variations of ion density. For an isotropic electron distribution, charge neutrality can be maintained only means of electric fields along the lines of force of the order of $kT_e$ per ion Larmor radius. Such random fields give rise to resistivity proportional to $(T_e/n_e)^{\frac{1}{2}}$ and consistent in magnitude with observations in pinch experiments.

**J7. Vacuum Ultraviolet Measurements on a Linear Pinch.*** R. G. TUCKFIELD, JR., *General Atomic.*†—Optical measurements in the vacuum ultraviolet region have been made on a 14 cm bore 100 cm long linear pinch. In the region of 400 to 3000 A the OVI $2p$-$2s$ resonance lines were observed to be about 25 times the intensity of Lyman alpha, just after the first current peak. Lower ionization levels of oxygen as well as CIV and NV were also observed. Results will be given of impurity light as a function of radius looking along the $Z$ axis.

* Research on controlled thermonuclear reactions is a joint program carried out by General Atomic and the Texas Atomic Energy Research Foundation.

† John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

**J8. Energy Loss Measurements in the Far Vacuum Ultraviolet from a Toroidal Pinch Discharge.*** J. OSHER, E. KNAPP, AND H. KARR, *Los Alamos Scientific Laboratory.*—Motivated by the prohibitive energy losses appearing in stabilized pinch discharges, the electromagnetic spectrum emitted from Perhapsatron S-4 has been investigated. Measurements have been made using a thermistor bolometer for time integrated radiation and a windowless vacuum photocell for time behavior. Essentially complete absorption by a 2000 A thick zapon filter identifies the dominant radiation as being in the far ultraviolet. The bolometer signal corresponds to an integrated energy flux of $\sim 75\%$ of the initial stored condenser energy being radiated to the walls; this, within errors, accounts for the total energy input to the gas. The vacuum photocell signal corresponds to a total flux of $10^{20}$ photons/$\mu$sec to the torus walls under normal operating conditions with an average photon wavelength of 210 A. The ultraviolet signal from the

photocell shows a distinct delayed onset time, this delay time being primarily a function of the initial gas impurity. The amplitude of the signals from either the bolometer or photocell measurements varies proportionately to the square of the condenser bank voltage.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**J9. Energy Distribution in the Radiation Spectrum from a Toroidal Pinch Discharge.*** H. KARR, J. OSHER, AND E. KNAPP, *Los Alamos Scientific Laboratory.*—The intensity distribution in the electromagnetic radiation spectrum from the Perhapsatron S-4 toroidal discharge is described. Only about 1% of the initial capacitor bank energy is lost in the infrared, visible, and x-ray regions of the spectrum and an electron energy loss of about one joule is associated with the x-ray production. The only significant radiation loss ($\sim$75% of total energy input to discharge system) is observed in the vacuum ultraviolet region. Identification of the ultraviolet radiation as bound-bound radiation largely from ionized oxygen and silicon impurities is determined with an 0.5 m grazing incidence vacuum spectrograph. Strong line emission from ionized states of oxygen (OI through OVI) and of silicon (SiI through SiIV) over the spectral interval between 75 to 1100 A is observed. The time behavior of the contaminant radiation in the various states of ionization is described. Effects of introduced impurities on the time behavior and intensity distribution of the spectral lines are also examined. The time of appearance of the oxygen and silicon emission depends on the quantity of initial impurity of nitrogen or helium in the gas indicating that the initial impurity can give rise to additional contaminants from the walls of the system.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**J10. Mechanism for Impurity Radiation Growth in a Pinch Discharge.*** E. KNAPP, H. KARR, J. OSHER, AND E. STOVALL, *Los Alamos Scientific Laboratory.*—The detailed data on ultraviolet radiation from the Perhapsatron S-4 toroidal discharge are analyzed in terms of possible models to explain its behavior. These data indicate the mechanism must (1) give a radiation loss onset time primarily dependent on the initial impurity present in the discharge gas, (2) be independent of the flutter time usually associated with instabilities, (3) give an onset time independent of the rate of rise of current, (4) be capable of injecting large quatities of impurity into the discharge after the pinch is well away from the tube wall, and (5) have a saturation property such that both the rate of emission and total radiation emitted are proportional to the energy input. A possible mechanism is proposed which utilizes an exponential growth in impurity level due to the release of adsorbed gases and wall materials from the wall by hard ultraviolet radiation. Correlations between the exponential results and this model will be made with the assistance of a quasi-equilibrium theory of impurity radiation worked out by Knorr.[1] Other possible mechanisms will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] G. Knorr, Z. Naturforsch., 13a, 941–950 (1958).

**J11. Self Pinching of a Current through a Plasma in a Solid.** MURRAY A. LAMPERT, *RCA Laboratories.*—The current carriers in a fully mobile plasma in a semiconductor are the electrons in a conduction band and the holes (missing electrons) in a valence band. The semiconductor plasmas most useful for self-pinching experiments differ greatly from their gaseous counterparts in having: (i) low percentage of ionization, $10^{14}$–$10^{16}$ cm$^{-3}$ carrier-density compared to a "neutral" density $\simeq 10^{22}$; (ii) short recombination lifetimes, $<10^{-5}$ sec; (iii) low maximum electron and hole temperatures, $<0.2$ ev; (iv) small collision times, $<10^{-10}$ sec above 77°K; (v) "low" power-input limitations dictated either by thermal interference with the experiment or ultimately by thermal destruction of the material. Semiconductor plasmas may be generated in a variety of ways; (a) thermal generation (intrinsic semiconductor); (b) double-injection (simultaneous injection of electrons from a cathode and holes from an anode); (c) field-induced electrical breakdown (collision ionization across the band gap); (d) carrier generation by bombardment (by light quanta or electrons). Considerations, (i)–(v) strongly favor (c) and (d) as a means to study self pinching in semiconductor plasmas. It is significant that residual space-charge in the semiconductor plasma, though percentage-wise very small, can nevertheless, due to the smallness of the pinching force, inhibit pinching, as for example with method (b).

**J12. Experiments Relating to Plasma Pinch Effects in Solids.** M. GLICKSMAN AND M. C. STEELE, *RCA Laboratories.*—Electron-hole plasmas have been generated in $n$-type InSb by collision ionization across the forbidden gap. Experiments on such plasmas in the presence of longitudinal magnetic fields suggest that pinch effects exist when the current exceeds a critical value. Pulses of 1 $\mu$sec duration and low repetition rate were used to minimize heating effects. Since the current did not change during the pulse duration it is evident that the period of quasistability of the pinch must be at least 1 $\mu$sec. When the applied longitudinal magnetic field exceeded the azimuthal current-produced magnetic field the pinch was essentially destroyed. Additional experiments with less pure $p$-type InSb and $n$-type InAs showed collision ionization but no pinch effect. The probable explanation of such results will be discussed.

**J13. Liquid Sodium Hydromagnetic Equilibrium Measurements.*** F. O. HALLIDAY, S. A. COLGATE, AND H. P. FURTH, *Lawrence Radiation Laboratory, Livermore.*—Equilibrium surfaces between a rapidly oscillating magnetic field and a "diamagnetic" fluid (liquid sodium) can be recorded by freezing the sodium after the desired equilibrium surface is achieved. A casting can then be made for accurate analysis. In the simple case where an $H_0$ magnetic field surrounds a vertical cylindrical rod, the shape and stability of the equilibrium surface between the field and the surrounding liquid sodium can be predicted theoretically and have been checked experimentally. The effective specific gravity of the liquid sodium is controlled by immersing the sodium in an oil of similar mass density. In order to demonstrate that neither magnetic skin depth nor surface tension restricts the growth of instabilities, the oscillating field can be applied in a series of discrete pulses. The resultant short time acceleration of the liquid metal surface causes $m=0$ Taylor-type instabilities to grow, in agreement with theory. More general configurations, for which stability and surface configuration are not analytically obvious, are being performed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**J14. Experimental Analog Study of Plasma Core Three-Dimensional Equilibrium.*** A. J. HATCH AND J. W. BUTLER, *Argonne National Laboratory.*—The mathematical treatment of the three-dimensional equilibrium properties of a plasma core isolated from the material walls of a resonant cavity by an interposed electromagnetic field is limited by complexity to only a few special cases, namely those in which core perturbations are restricted to infinitesimal changes from initial configurations allowing ready solution of the electromagnetic field equations. For cases involving finite core changes, however, an analog experiment can more conveniently furnish equilibrium information. Plasma cores simulated by metallic

bodies are mechanically suspended in a cavity whose modes are excited by a test signal. Frequency shifts associated with core perturbations are observed. Consideration of adiabatic invariance and pressure balance permit the interpretation of positive, zero, and negative frequency shifts as indicative of stable, neutral, and unstable equilibrium, respectively. Such an analog experiment has been performed for plasma cores simulated by copper spheres and spheroids in a 24-in. diam spherical cavity with stationary modes excited in the 400 to 1000 Mc range. A typical result is that for the $TE_{110}$ mode a spherical core exhibits stable size equilibrium but unstable position and configuration equilibrium.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

## SATURDAY AFTERNOON AT 2:00

## Spanagel Hall

## (J. E. DRUMMOND presiding)

**K1. Adiabatic Theory of Plasma Betatrons.** GEORGE SCHMIDT, *Stevens Institute of Technology.*—The formation of a relativistic plasma thread by means of a plasma betatron[1] is described, using a self-consistent field method. The betatron accelerates ions and electrons on the same equilibrium orbit, but in the opposite direction giving rise to a self current, with a strong focusing pinch field. The plasma is confined essentially by the self field, produced mainly by the relativistic electrons. A self-consistent field calculation is carried out by solving simultaneously the equations of motion of particles (neglecting collisions) and Maxwell's equations, for both the relativistic and nonrelativistic region. Formulas are obtained for the beam contraction, transverse temperature, critical particle density for pinching, radial beam collapse, etc. It is shown that in the absence of collisions, the beam undergoes oscillations of the thread minor radius, which couples with radial oscillations of the plasma ring.

[1] W. H. Bennett, U. S. Naval Research Lab. Report 203 (1953); G. J. Budker, CERN Symposium (1956).

**K2. A Theory on Hydromagnetic Homopolar Device.** C. C. CHANG AND T. S. LUNDGREN, *University of Minnesota.*—Recently Baker and his associates of Lawrence Radiation Laboratory of Berkeley published a paper on hydromagnetic capacitor usually called homopolar device. In response to their work, a mathematical theory is developed and presented in this paper. First the properties such as the flow velocity and induced magnetic field of some steady and transient limiting cases are given. Then, the over-all properties such as resistance, capacitance and charging time are calculated and the equivalent circuit is given. Two interesting results are: (a) For a large applied magnetic field viscous dissipation and joule dissipation contribute equal amounts to the total rate of dissipation. (b) For a given geometry of the device, the maximum plasma kinetic energy can be found as a function of Hartmann number.

**K3. Sheaths, Probes, and Related Space Charge Behavior.** LOUIS GOLD,* *Project Matterhorn, Princeton University.*—Several aspects of space charge structure connected with sheaths and probes have been investigated with the prospect of ultimately comprehending the complex role of a superposed magnetic field. An analytic solution for the classical Langmuir sheath has been secured and the stability question more closely examined. The formalism relates to several earlier studies.[1] Collision-dominated behavior for the dense plasma will be compared with the conventional collision-free regime. Both the modified structure of sheaths and probe response produced by a magnetic field have been explored, and some possible tractable cases will be discussed.

* Supported in part by Convair Division, General Dynamics, San Diego, California.

[1] L. Gold, J. Electronics and Control, **5**, 327, 432 (1958).

**K5. Analysis of a Plasma Accelerator, Including Resistive Effects and Mode-Switching.*** PHILIP M. MOSTOV, JOSEPH L. NEURINGER, DONALD S. RIGNEY, *Plasma Propulsion Laboratory, Republic Aviation Corporation.*—A pulsed plasma accelerator is analyzed. The slug model is emphasized. Employing a constant source resistance $R_0$, and a *variable* wall resistance whose gradient $R_1$ is later specified constant, a system of coupled nonlinear equations involving 7 parameters are derived and transformed into a 3-parameter set. This formulation provides a more realistic bases than, and includes as special cases, Artsimovitch's treatment ($R_0=R_1=0$), and Schock's approximate *periodic* mode treatment ($R_1=0$) which is valid in many cases after $\frac{1}{4}$ cycle. Wide ranges of operating conditions and parameters are considered. Curves of plasma position, velocity, efficiency $\epsilon$, utilization factor $\eta$, voltage, current, and frequency are given. Periodic and aperiodic modes, as well as mode-switching and *switch-backs* during the acceleration, are possible. Criteria are given. In one typical case, including $R_0$ lowers the ultimate $\epsilon$ from an unrealistic 100% implied by $R_0=R_1=0$ to 30%; including $R_1$ further lowers $\epsilon$ by 25%. Optimum cutoffs are discussed. $\eta$'s almost equal to the highest obtainable in a particular case frequently can be achieved with practical lengths by terminating at local peaks.

* Supported in part by the Office of Scientific Research and the Office of Naval Research.

**K6. Ionic Centrifuge and Fusion Nuclear Power.** JOSEPH SLEPIAN, *1115 Lancaster Street, Pittsburgh 18, Pennsylvania.*—The ionic centrifuge is a low voltage arc source of ionization maintained in a vacuum between long electrodes at the center of a rather long circular cylinder through which a longitudinal magnetic field passes. The end plates which bound the vacuum space longitudinally are maintained at one voltage; the cylinder which bounds the space circumferentially is maintained at another voltage. The discharge in this device violates the usual rules for magnetohydrodynamics because of the high electric field parallel to the magnetic field in the space charge affected boundaries. The kinetic energy of random motion of the particles is proportional to the voltage which the main discharge holds at each point. By making this voltage rise to a high positive value and then drop to zero at the cylinder, the ions are not collected when their kinetic energy is high, but only at the cylinder where this kinetic energy is low again. The suitability of this arrangement for nuclear power convertors is pointed out.

## SUPPLEMENTARY PROGRAMME

**KS1. Ion Wave Instabilities.** IRA B. BERNSTEIN,* EDWARD A. FRIEMAN,*† AND RUSSELL M. KULSRUD,* *Project Matterhorn, Princeton University* AND MARSHALL N. ROSENBLUTH,† *General Atomic Division of General Dynamics Corporation.*—Recent experimental evidence[1] on the Project Matterhorn B-3 stellarator has indicated the existence of a rapid particle loss which has been attributed to some sort of enhanced diffusion across the magnetic field. Spitzer[2] has pointed out that low frequency ion waves excited above thermal equilibrium levels could give rise to anomalously large diffusion of a plasma across a magnetic field. A low frequency ion wave instability has been found which can occur during the time the particle loss is observed, and which can give rise to excitation of ion waves above thermal equilibrium levels. The approximations made and the dispersion relation obtained will be discussed. In addition, a diffusion coefficient can be calculated using Spitzer's picture and order of magnitude arguments. A comparison of these results and the experimental results on the B-3 stellarator will be made.

* Supported by the U. S. Atomic Energy Commission.
† Supported by a contract between General Atomic and the Texas Atomic Energy Research Foundation.
[1] R. A. Ellis, L. P. Goldberg, and J. G. Gorman, Phys. Fluids (to be published).
[2] L. Spitzer, Jr. (private communication).

**KS2. Hydromagnetic Stability of Stationary Equilibria.** E. FRIEMAN* AND M. ROTENBERG*† *Project Matterhorn, Princeton University.*—Previous work[1] on an energy principle for hydromagnetic stability problems was restricted to the case of static equilibria. It is, therefore, of interest to investigate hydromagnetic stability when this restriction is removed. A general sufficient condition for stability has been found which applies to stationary equilibria. The sufficient condition leads to the following theorem: If a static equilibrium state is stable, the addition of any velocity field which satisfies the equilibrium equations and which is small compared to both sound and Alfvén speeds, leaves the system stable. If the static equilibrium state is neutral, a simple necessary and sufficient condition for stability has been derived. This condition leads to a proof that to lowest order in the parameter of smallness overstability cannot occur. If the static equilibrium state is unstable, a small velocity field can produce overstability but not stability.

* Supported by a contract between Princeton University and U. S. Atomic Energy Commission.
† Permanent address: University of Chicago.
[1] I. B. Bernstein, E. A. Frieman, M. D. Kruskal, and R. M. Kulsrud, Proc. Roy. Soc. (London) **244**, 17 (1958).

**KS3. Theory of a Pulsating Compressible Plasma.*** R. L. MOORE, *Richard L. Moore Consultants.*—A theory of plasma compressed by electromagnetic fields is based on Newton's third law.[1] Continuity of action gives boundary conditions which are developed as a compressional force and a moment of force leading to rotary motion. The fluid is treated by nonviscous hydrodynamics.[2] Collective ion motion is found corresponding to Alfvén waves, and to sound-like waves, in the *velocity*, which transfers momentum to a distance. The possible significance of waves of the frequency of light in an electron gas will be discussed. Plasmas of cylindrical, slab, and spherical geometry, with small angular motion, pulsate as follows:

$$\frac{\partial^2 v}{\partial t^2}+av\frac{\partial v}{\partial t}+bv^3+f(t)v+g(t)=0.$$

$v$ is the time-dependent function of the velocity perpendicular to the surface. Asymmetries can lead to a helical motion of the axis of a cylindrical plasma.

* Work supported by Norair Division, Northrop Corporation.
[1] As given by E. G. Cullwick in *Electromagnetism and Relativity* (London, 1957), Chap. 17.
[2] S. Rosseland, *Pulsation Theory of Variable Stars* (Oxford, 1949).

**KS4. Stability of Helically Invariant Fields from the Particle Picture.*** RUSSELL M. KULSRUD, *Project Matterhorn, Princeton University.*—General hydromagnetic equilibria in the neighborhood of a cylindrical equilibrium are described from the particle point of view. The stability of these equibria has already been calculated from the fluid equations and is here recalculated on the basis of a particle picture. The calculation is based on an energy principle developed by Kruskal and Oberman, and independently by Rosenbluth and Rostoker. However, the effect of charge neutrality is taken into account in a way shown by Newcomb. The stability results found were identical for the two calculations in the case of equilibria with scalar pressures. Otherwise they were similar unless the perpendicular pressure is much larger than the parallel pressure. In the latter case the "mirror-type" instability of Newcomb is found.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

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## SATURDAY AFTERNOON AT 2:00

### King Hall

(P. R. BELL presiding)

**L1. Penetration of a Magnetic Barrier by a Plasma Jet.** M. A. GILLEO, *Missiles and Space Division, Lockheed Aircraft Corporation.*—The problem of penetration of a magnetic barrier $B_1$ by a plasma jet along the axis of an otherwise uniform magnetic field $B_0$ has been examined. A plasma in thermal equilibrium in $B_0$ contains ions and electrons of magnetic moment $\mu=mv_t^2/2B_0$, where $v_t$ is the Maxwellian transverse velocity. A jet of axial velocity $u^0$ incident on the magnetic barrier $B_1 \ll B_0$ exhibits a charge separation because the ions have a kinetic energy which approaches $m_i/m_e$ times that of electrons while both have the same magnetic moment which is adiabatically invariant for the conditions considered. The charge separation introduces electric potential energies $\pm eV$ of opposite sign for ions and electrons while the magnetic potential energies $\mu B$ are the same for both. $V$ is determined by the condition that the ion and electron currents be equal in and out of the region of the magnetic barrier. The electric potential brings about an acceleration of electrons through the barrier at the expense of the kinetic energy of the ions and thereby accounts for much of the force exerted on the ions by

the magnetic barrier. Particle density and temperature are considered in a range where the effects of collisions and of magnetic shielding by plasma currents may be neglected.

**L4. Determination of Ion Rotational Energy Distributions of Plasma in a Uniform Magnetic Field.*** A. E. SHERMAN, F. H. COENSGEN, W. E. NEXSEN, AND W. F. CUMMINS, *Lawrence Radiation Laboratory, Livermore.*—A method of measuring the rotational energy distributions of plasma ions in a uniform magnetic field is described. The method is based on the adiabatic law of reflection of charged particles by a magnetic mirror. The experimental system consists of a 20 ft long vacuum chamber, of 18 in. diam, provided with a uniform longitudinal magnetic field. A magnetic mirror of 7000 gauss can be established at the center without disturbing the conditions at either end. Plasma is injected or generated at one end of the system and detected by a large extraction probe or an ion energy analyzer at the other end. Angular distributions have been determined for various injection conditions using 800 ev plasma generators. For a single generator aligned with the field the widest angular distribution is obtained with the highest magnetic field. Detailed investigation at 400 gauss revealed that the angular distribution of the energetic ions is greater than that of the low energy ions. For the cross field injection arrangements studied, the angular distributions were not improved over the longitudinal injection.

* Work done under the auspices of the U. S. Atomic Energy Commission.

**L5. Experiments on Plasma Flow into a Vacuum Cusp Geometry.*** F. R. SCOTT, R. E. WENZEL, W. R. SNOW, AND J. A. RUTHERFORD, *General Atomic.*†—Apparent confinement of plasma has been observed optically in a cusp geometry.[1,2] The plasma was injected with a velocity of $8\times10^6$ cm/sec by means of a conical discharge tube and a fast electromagnetic gas injection valve. The cusp axis was parallel with that of the cylinder. Time-dependent photographs show intense light emission at the center of the cusp with considerably less emission from regions of high magnetic field and very little total light from regions beyond the cusp. Observation of $D_\beta$ showed pressure broadening in the central cusp region. Emission of the central portion of $D_\beta$ was observed for a least 50 $\mu$sec. Without the cusp no observable broadening occurred and the $D_\beta$ light lasted for only 20 $\mu$sec. Data on impurity light, magnetic probes, ejected particle momenta, and confinement times will be presented.

* This work was carried out under a joint General Atomic-Texas Atomic Energy Research Foundation program on controlled thermonuclear reactions.
† Division of General Dynamics Corporation.
[1] Harold Grad, U. S. Atomic Energy Commission Report, NYO 7969.
[2] J. L. Tuck, Phys. Rev. Letters 3, 313 (1959).

**L6. Plasma Injection into a Magnetic Cusp.*** F. H. COENSGEN, W. E. NEXSEN, W. F. CUMMINS, AND A. E. SHERMAN, *Lawrence Radiation Laboratory, Livermore.*—As pointed out recently[1] there are two principal problems in the use of a magnetic cusp for confinement of an externally generated plasma. First, the plasma must penetrate into the cusp region and second it must be trapped there. These problems have been investigated experimentally, using the plasma stream from an 800 ev plasma generator. The generator was located in a zero magnetic field and aligned along the axis of symmetry. Electric extraction probes were used to detect the plasma. Approximately half of the plasma penetrates into the cusp whether or not the magnetic field between the cusp and the generator exceeds the calculated critical field, $B_c=12\pi\rho_0 v_0^2$. $\rho_0$ is the plasma density and $v_0$ its translational velocity. Again, at least half of that reaching the cusp promptly penetrates the larger magnetic field beyond the midplane. Large prompt signals are detected by a detector in a side arm of the vacuum chamber at the midplane of the cusp.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] J. L. Tuck, Phys. Rev. Letters 3, 313 (1959).

**L7. Transient Development of a Cusped Plasma.** JEROME BERKOWITZ. *New York University, Institute of Mathematical Sciences* (introduced by H. Grad).—We give a theoretical analysis of the transient development of a cusped high $\beta$ plasma configuration while a plasma beam is injected into it. Using previous results[1] on cusped geometries, we estimate the maximum pressure, temperature, and size of the limiting cusped configuration.

[1] J. Berkowitz, K. O. Friedrichs, et al., Proc. Second Intern. Conf. Peaceful Uses Atomic Energy, Geneva, 1958, 31, 171 (1958).

## SUPPLEMENTARY PROGRAMME

**LS1. Acceleration of a Plasma by Time-Varying Magnetic Fields.*** R. F. POST, *Lawrence Radiation Laboratory, Livermore.*—Some aspects of the one-dimensional acceleration of a plasma by axially symmetric time-varying magnetic fields are considered theoretically. The basic acceleration mechanism is described in terms of a simple, single, equation, which should be approximately valid for many cases of practical interest. This equation shows that, for the cases to which it applies, each linear element of the plasma behaves as a single "super particle" possessing a magnetic moment and mass equal to the mean of the magnetic moments and masses, respectively, of all the plasma particles in that element. Since the magnetic acceleration processes considered are coupled through the magnetic moments of the particles themselves, it follows that the acceleration forces cannot be made arbitrarily large. This results in some practical limitations on the achievable plasma velocities which are described in terms of scaling parameters and particular examples.

* Work done under the auspices of the U. S. Atomic Energy Commission. Some of the material in this paper is derived from UCRL-4407 (December, 1954) of the same title.

**LS2. Evidence for Hydromagnetic Kink Instability in the B-1 Stellarator. II.*** W. BERNSTEIN, A. Z. KRANZ, AND F. TENNEY, *Project Matterhorn, Princeton University.*—The range of plasma current, over which each specific oscillatory mode occurs, is found to be in excellent agreement with the theoretical prediction for the corresponding mode of the hydromagnetic kink instability.[1] Since the onset current for each instability mode corresponds to a $2\pi/m$ degeneracy in the magnetic field, it is also possible that the observed phenomena result from this degeneracy rather than from hydromagnetic instability.

Detailed measurements for the $m=1$ mode indicate tha the plasma is deformed into a helix, and that the helix then rotates as a rigid body; the observed oscillations arise as a result of the rotation. Evidence will be presented to show that the oscillations for the other modes also arise from the rotation of the distorted plasma.

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. D. Kruskal, J. L. Johnson, M. B. Gottlieb, and L. M. Goldman, Phys. Fluids 1, 421 (1958).

**LS3. Hydromagnetic Injection of Charged Particles into Uniform Magnetic Field.** C. C. CHANG, *Lawrence Radiation Laboratory, Livermore and University of Minnesota.*—A new scheme of injecting charged particles into a thermonuclear device such as Astron is described. The injection can be carried out at small or even zero injection angle and the orbiting particles are estimated not to hit the injection system. Therefore it can be kept safely at reasonably large radial clearance from trajectory envelope of the charged particles such as the location of the cylindrical $E$ layer.

The method can be applied to injection of charged particles of any energy level. Beside the regular electron gun, the attachments are simple economical and easy to develop.

## POST-DEADLINE PAPERS

**Preionized Operation of Scylla.*** W. E. QUINN, E. M. LITTLE, F. L. RIBE, AND J. L. TUCK, *Los Alamos Scientific Laboratory.*—By means of a preionizing axial discharge, those features of Scylla's operation previously observed during the second half cycle of its magnetic compression field[1] have been advanced to the first half cycle. When in addition a dc axial magnetic field $B_z$ of a few kilogauss is applied antiparallel to the Scylla field, neutron emission is observed[2] during the first (and second) half cycle with the usual symmetrical time distribution. The neutron yield increases exponentially with $B_z$ for $B_z \lesssim 3$ kg and increases more slowly for larger values. No neutrons are observed during the first half cycle with $B_z$ parallel to the Scylla field. Probes show the compression magnetic field to be excluded from the central region of the coil for an appreciable fraction of the normal rise time. Streak photographs show a radial "shock" ($1.2\times10^7$ cm/sec) at the beginning of the first half cycle.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] K. Boyer, E. M. Little, W. E. Quinn, G. A. Sawyer, and T. F. Stratton, Phys. Rev. Letters **2**, 279 (1959).

[2] See for comparison A. C. Kolb, C. B. Dobbie, and H. R. Griem, Phys. Rev. Letters **3**, 5 (1959).

**Resonance in a Plasma with Two Ion Species.** S. J. BUCHSBAUM, *Bell Telephone Laboratories.*—When a plasma column in an axial magnetic field possesses two (or more) ion species of different charge to mass ratios, there exists a plasma resonance condition which involves only the ion cyclotron frequencies. At resonance, the two ion clouds oscillate transversely to the magnetic field and 180 degrees out of phase with each other while the electrons remain relatively motionless. The ratio of the ion oscillatory energy to that of the electrons is of the order of the ratio of the ion to electron masses. Collisions between the two ion clouds randomize the large ordered velocities of the ions with great efficiency. Thus, by exciting this resonance considerable ion heating may be realized. The effect of varying the relative concentration of the two ions is discussed.

**Effect of Radiofrequency Preionization on Neutron Production by a Fast Magnetic Compression.** E. HINTZ, H. FAY, AND H. JORDAN, *Technische Hochschule, Aachen, Germany.*—The influence of pulsed rf on the fast magnetic compression of a deuterium plasma was investigated with the following parameters: 5 kilojoules, $L \lesssim 2$ $m\mu h$, 25 kv, coil length and radius 16 cm and 2 cm, gradient 1.5 kv/cm. The internal axial magnetic fields were observed with a radial probe 2.5 cm from the central plane of the coil. Without rf, $10^6$ neutrons/pulse were measured during the second and third half cycles for 55 and 37 $\mu$, respectively. (The yield was an order of magnitude smaller at 75 $\mu$ and not detectable at 100 $\mu$.) The neutron pulse was not influenced by the probes. Two groups of neutrons were observed. At 37 and 75 $\mu$ the neutron emission was associated with large $\dot{B}$ fluctuations and hard x rays ($\sim$100 Kev). However, no x rays of $\dot{B}$ fluctuations could be observed during neutron emission for 55 $\mu$. In this case, there was no reversed field and the $\beta$ was low. With preionization by a high voltage (10–20 kv), 10 Mc/sec rf pulse, the neutrons disappeared totally at 55 and 75 $\mu$. At 37 $\mu$, the preionization shifted the neutron emission to the second half cycle. These results show that the initial conditions are of critical importance and may completely change the behavior of the discharge. The neutrons seem rather to be due to some acceleration mechanism than to a high temperature plasma.

### *Pertaining to the Oliver E. Buckley Solid-State Physics Prize*

*(Item added to proof, and not proofread)*

By order of the Council, members of the Society are invited to propose candidates for the 1961 Oliver E. Buckley Solid-State Physics Prize, and this they may do by writing to Dr. Conyers Herring, Bell Telephone Laboratories, Murray Hill, New Jersey, who is Chairman of the Committee appointed to nominate candidates.

This prize is to be awarded for the making of "a most important contribution to the advancement of knowledge in solid-state physics" during the five years immediately preceding the award and "in the United States of America and its possessions or in the neighboring countries included in the continent of North America and its insular environs." No stipulation is made as to the nationality of the prize-winner. The prize may not be divided between two or more recipients.

Similar announcements about other prizes will be made in future issues of this Bulletin.

## MEETINGS AND DEADLINES THROUGH AUTUMN 1960

| *Place* | *Meeting dates* | *Deadline date* |
|---|---|---|
| Detroit | March 21–24 | Past |
| Washington | April 25–28 | Past |
| Montreal | June 15–17 | April 8 |
| Chicago | November 25–26 | undecided |

Abstracts for the meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. *Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west.* Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected. No abstract postmarked (at the point of dispatch) on deadline day ever reaches the office on time, nor does any abstract postmarked at any point west of the Rockies on the day before deadline day. Some abstracts arrive with covering letters dated three or more days before the postmark; it may be a good idea for you to put your abstract into a United States mail box with your own hands. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

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## TOPICAL CONFERENCES (see above)

| | | | |
|---|---|---|---|
| Gatlinburg | Neutron diffraction | April 20–22 | past |
| Gatlinburg | Reactions between Complex Nuclei | May 2–3–4 | April 2 |
| Monterey | Gaseous Electronics | October 12–14 | August 24 |

## RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words or to its actual length in words, whichever is the greater; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original*, the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

### *New Instructions*

(*a*) *If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."*

(*b*) *If a member insists that his paper be scheduled for a particular day or not on a particular day, he will get his wish, but usually at the price of having his contribution included in a session to which it is irrelevant.*

(*c*) *The Secretary and his deputies have been empowered by the Council to count a footnote either as ten words or as its actual length in words, whichever is the greater length.*

(*d*) *In general, all instructions about an abstract should be typed at the bottom of the page that has the abstract on it,* never *in a covering letter. Covering letters get separated from abstracts!*

(*e*) *Always write your name the same way. Do not use initials in one abstract and then spell it out in another. This complicates indexing. It is preferable to give your name in full.*

# The American Physical Society

## OFFICERS OF THE SOCIETY FOR 1960

| | | |
|---|---|---|
| *President* | V. F. Weisskopf | Massachusetts Institute of Technology |
| *Vice-President* | Frederick Seitz | University of Illinois |
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| *Treasurer* | S. L. Quimby | Columbia University |
| *Managing Editor* | S. A. Goudsmit | Brookhaven National Laboratory |

*Past Presidents now on Council:* W. F. G. Swann, H. D. Smyth, J. W. Beams and G. E. Uhlenbeck.

*Other members of the Council:* Walker Bleakney, W. K. H. Panofsky, W. A. Fowler, Charles Kittel, Harvey Brooks, Charles Hard Townes, N. E. Bradbury and D. W. Kerst.

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| *Local Secretary for the Pacific Coast* | W. A. Nierenberg | University of California, Berkeley |
| *Deputy Secretary* | W. W. Havens, Jr. | Columbia University |